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Multi-Scale Action Effectiveness Research in the Lower Columbia River and Estuary, 2011

FINAL ANNUAL REPORT

Pacific Northwest National Laboratory
Oregon Department of Fish and Wildlife
National Marine Fisheries Service
University of Washington

May 2012

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Multi-Scale Action Effectiveness Research in the Lower Columbia River and Estuary, 2011

Final Annual Report

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Executive Summary

The study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL), the Oregon Department of Fish and Wildlife (ODFW), the University of Washington (UW), and the National Marine Fisheries Service (NMFS) for the U.S. Army Corps of Engineers, Portland District (USACE). This research project was initiated in 2007 by the Bonneville Power Administration to investigate critical uncertainties regarding juvenile salmon ecology in shallow tidal freshwater habitats of the lower Columbia River. However, as part of the Washington Memorandum of Agreement, the project was transferred to the USACE in 2010. In transferring from BPA to the USACE, the focus of the tidal freshwater research project shifted from fundamental ecology toward the effectiveness of restoration in the Lower Columbia River and estuary (LCRE). The research is conducted within the Action Agencies' Columbia Estuary Ecosystem Restoration Program (CEERP). Data reported herein spans the time period May 2010 to September 2011.

Purpose and Objectives

The purpose of this study was to provide site-scale pre-restoration research for the proposed rechannelization of the Sandy River delta (SRD) and to evaluate landscape-scale conditions for juvenile salmon between the confluences of the Lewis and Cowlitz rivers in the lower Columbia River. Objectives for the 2010–2011 reporting period were as follows:

1. Perform site-specific action effectiveness research to evaluate controlling factors, ecosystem structures, and functions in the SRD and vicinity in anticipation of the rechannelization restoration, including environmental conditions, fish community composition, salmon density and lengths, genetic stock identification, and water chemistry.

   1.a. Characterize the diets of juvenile Chinook salmon and abundant resident fish species.

   1.b. Describe the compositions of prey pools in tidal freshwater habitats of the LCRE.

2. Compare fish communities, salmon catch proportions and lengths, and salmon densities at the landscape scale between two areas of the LCRE.

3. Estimate the mean residence time of large (95−125 mm) salmon that are present during winter months at the SRD and in the vicinity.

Methods

Sampling for our study occurred within two distinct areas of the tidal freshwater segment of the LCRE: the SRD and the Lower River Reach (LRR) area. Four sites at the SRD were sampled monthly, except when high flow conditions prevented data collection efforts (e.g., May and June 2011). In the LRR, a random stratified sampling design was implemented seasonally across three habitat strata (main channel, off channel, and wetland channel) within a rotational panel design. As in conducted during past research efforts, this project collected data relevant to the following: fish community composition, fin clips for genetic stock identification, gastric lavage for diet analysis, prey availability for feeding behavior, water chemistry for environmental conditions, and acoustic telemetry for residence time.

Findings

Total catch at the SRD from May 2010 to September 2011 consisted of 26 species, of which 13 were non-native fishes. In terms of total numbers of fish captured, catches predominantly comprised native taxa, but non-native constituents accounted for approximately 21% of the total catch. Summer 2011 yielded the highest densities for native taxa (excluding salmon) while salmon were most predominant during spring 2010 and 2011 months. Four species of salmon and trout, unmarked and marked, were captured at the SRD sites during the May 2010–September 2011 time period. Unmarked Chinook salmon were the most abundant. The patterns associated with length frequency distributions of unmarked Chinook salmon captured in shallow water habitats indicated distinct temporal trends. During winter months, unmarked Chinook salmon occupied two size-class groups that are indicative of different life stages. Winter and spring yielded the smallest sizes of unmarked Chinook salmon. In terms of genetic stock composition, most of the unmarked Chinook salmon captured at the SRD were from the Upper Columbia Summer/Fall (35%) and the Spring Creek Group Tule Fall (31%) stock groups. Smaller proportions were estimated for the Willamette River Spring (15%) and West Cascade Tributary Fall (7%) groups. Deschutes River Fall (6%), West Cascade Tributary Spring (3%), and Snake River Fall (2%) fish were also sampled.

Despite considerable variability in both space and time, the diets of juvenile Chinook salmon sampled at our sites from May 2010 through September 2011 generally were dominated by five groups: dipterans (primarily chironomids and ceratopogonids), cladocerans (largely bosminids), amphipods, odonates, and hemipterans. Of these taxa, dipterans most frequently constituted large proportions of gut content biomass, accounting for more than 20% of Chinook salmon diet during 11 of 21 (52%) sampling episodes. The most important prey taxa in the diets of Chinook salmon, as indicated by the IRI, included dipterans, amphipods, and cladocerans, although the importance of these prey items were variable over time. These taxa were never consumed in proportion to their abundance in the environment across the three prey pools considered in analyses. While dipterans consistently accounted for large proportions of prey in gut contents of juvenile salmon, with relatively few exceptions, juvenile salmon selected against these prey items. Dietary overlap was generally weak across our sites during months in which the gut contents of both Chinook salmon and resident species were collected. There were only two instances in which overlap was significant; during July 2011 the diets of both killifish and stickleback overlapped significantly with that of Chinook salmon.

We noted several spatial and temporal trends in the water property data at the SRD. Seasonal differences were observed throughout the year at all sites and were greater than site-specific differences, with the exception of Site N. For each sampling period, the water property attributes of Sites B, C, and E, were similar; but Site N was notably different (e.g., TSS, DO, POC, and nutrients) and exhibited higher variability than other sites. The lower surface water flow, hyporheic flow, and lack of connectivity to the main stem Columbia River at Site N may offer a partial explanation of the differences observed.

While the abundance and species composition sometimes differed between the SRD and LRR during the winter and summer sampling events, the proportions of salmon (~1%), native (~78%), and non-native taxa (~21%) were similar between the study areas. Similarities in fish assemblages across the study areas were best explained by season as opposed to site and/or habitat strata. As observed at the SRD, unmarked Chinook salmon were the most abundant salmon at the LRR sites and densities were greater in the summer compared to the winter sampling period. Size differences in unmarked Chinook salmon were observed across the study areas such that during February and July, the median fork length for unmarked

Chinook salmon captured at the SRD was larger compared to that for unmarked Chinook salmon captured at the LRR (Kruskal-Wallis test, $P < 0.001$). During February and July 2011, when both the SRD and LRR sites were sampled, the genetic stock compositions of the two study areas were markedly different. Most fish at LRR sites were estimated to be from the West Cascade Tributary Fall stock group, while the SRD sites were predominantly composed of the Upper Columbia Summer/Fall and the Spring Creek Group Tule Fall stock groups.

Our findings from 2011 support our previous work in that juvenile Chinook and coho salmon resided in the off-channel area behind Gary Island near the SRD for extensive periods from February through April. Median residence times were approximately 11 days for both Chinook and coho salmon. The mean residence times for Chinook and coho salmon were 25 and 29 days, respectively. One coho salmon stayed in the study area for almost 3 months and one coho salmon had not left before the nodes were retrieved on May 17, 2011. There was a non-significant negative relationship between fish length and residence time for Chinook salmon (P=0.284) and for coho salmon ($P = 0.115$).

CEERP Management Implications

This research, although designed to evaluate the effectiveness of restoration actions, has implications to the CEERP knowledge base. The results of our 2011 research will inform the 2012 CEERP Synthesis Memorandum. The memorandum is an annual work product from the CEERP process that is intended to provide a comprehensive compilation of science to date concerning juvenile salmon ecology and ecosystem restoration in the LCRE. In addition, our research to date has involved site-scale, pre-restoration sampling for the proposed rechannelization at the SRD and landscape-scale sampling in the LRR. While the restoration action is pending, the findings have these implications for particular CEERP uncertainties, as identified (italicized below) by the Action Agencies (2012).

- *"ecological interactions between juvenile salmon and other aquatic native and non-native aquatic and plant species; significance of these interactions and hybrid food webs are not clear (ISRP 2011)"*

  Our previous bioenergetics work on juvenile Chinook salmon at the SRD suggested that competition for prey resources may be weak (Storch 2011). Our current investigation of the diets of Chinook salmon and resident species (stickelback, killifish) indicates dietary overlap, during certain periods, was generally weak across our four sites. Our investigation was limited to the SRD, and should not be extended to other regions of the LCRE without additional investigation.

- *"juvenile salmon residence times, growth rates, and bioenergetics in tidal freshwater, estuarine, and main channel habitats"*

  Our research on residence time indicates juvenile salmon (Chinook and Coho) used tidally influence freshwater portions of the Lower Columbia River for extended times periods from mid-winter through early spring months. Our previous research on bioenergetics modeling (Storch 2011) at the SRD suggests feeding rates and gross conversion efficiency were sufficient for the allocation of energy to somatic growth for juvenile salmon.

- *"temporal and spatial abundance, stock composition, habitat use, and residency of unmarked and marked juvenile salmon"*

  We note distinct temporal trends in the abundance of juvenile salmon. While we capture several species of salmonids (e.g., chum, coho, steelhead) unmarked Chinook salmon were the most prevalent in our catches at both SRD and LRR study areas. Spring yielded the highest densities of juvenile salmon, the majority of which were quite small in size (e.g. fry to parr). Abundance of salmon generally decreased during summer and fall months but began to increase during winter. During winter months the bimodal size distribution of unmarked Chinook salmon denoted the co-occurrence of multiple life stages (e.g. fry and yearling) at the SRD.

- *"trends over time in landscape estimates of juvenile salmon density as related to multiple collective restoration actions"*

  Although an empirical analysis of landscape-scale salmon densities is premature for this report (because only one sampling event was available), we anticipate addressing this CEERP concern in future reporting.

- *"wintertime use of off-channel reference and restored areas, and extent and frequency of movements of juvenile salmonids from the main stem up into tributary areas; approximately what fraction of salmon populations use the habitats and for how long?"*

  Based on acoustic telemetry of tagged fish (>95 mm), juvenile salmon are residing in shallow, tidal freshwater habitats during winter (see Section 3.3.2 and Johnson et al. 2011). Future investigations to tag smaller juvenile salmon will provide further information on this topic. Investigations of up-tributary movements from the main stem are planned for 2012.

Recommendations

In closing, we offer the following recommendations for future elements of this ongoing study.

- Revisit the likelihood of the implementation of SRD rechannelization. If the prospects of restoration are low (<10% chance), prioritize and select new location(s) for site-scale AER in FY13.
- Coordinate with other researchers performing action effectiveness studies to reassess and prioritize the most useful and practical monitored indicators for ecosystem structure and function.
- Continue to identify genetic stocks of Chinook salmon sampled in shallow, tidal freshwater habitats to build a comprehensive genetics database in collaboration with other researchers in the LCRE.
- Coordinate with other research to assess the feasibility of implementing field based measures aimed at examining physiological attributes indicative of health and fitness of juvenile salmon in habitats of the LCRE.
- Design mark-recapture studies for juvenile salmon use of off-channel shallow-water sites, pre- and post-restoration.
- Given the extensive data set for this study (from 2007 into 2012), examine the statistical associations between juvenile Chinook salmon density (unmarked fish) and various environmental attributes, such as water temperature, habitat type, and vegetation percent cover.

Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL), the Oregon Department of Fish and Wildlife (ODFW), the National Marine Fisheries Service (NMFS), and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The PNNL, ODFW, NMFS, and UW project managers are Gary Johnson, Christine Mallette, David Teel, and John Skalski, respectively. The USACE technical lead is Cynthia Studebaker. The study was designed to evaluate the effectiveness of habitat restoration projects in the lower river and estuary at site- and landscape-scales. This annual report covers research conducted from May 2010 through September 2011. For more information about the study, please contact Cynthia Studebaker (503-808-4788).

A suggested citation for the report is:

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We are grateful for the contributions made by many individuals throughout the study. Jan Slater (PNNL) managed the contracts. The U.S. Forest Service allowed property access to sites at the Sandy River delta. From PNNL, Cynthia Wright provided data management support. Susan Ennor and Kathy Neiderhiser edited and formatted the report, respectively; Shon Zimmerman, Matt Hennen, and James Hughes were instrumental in the acoustics telemetry study. We especially acknowledge the dedication and hard work put forth for field by work by Charles Barr and Elizabeth Torrey from ODFW. Funding for the study was provided by the USACE under the Congressionally-appropriated Columbia River Fish Mitigation project.

Acronyms and Abbreviations

°C	degree(s) Celsius
2D	two-dimensional
AA	Action Agencies
APHA	American Public Health Association
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
chl-*a*	chlorophyll-*a*
d	day(s)
DO	dissolved oxygen
FCRPS	Federal Columbia River Power System
FL	fork length
g	gram(s)
h	hour(s)
IRI	Index of Relative Importance
ISAB	Independent Scientific Advisory Board
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
LCRE	Lower Columbia River and estuary
LRR	Lower River Reach
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mL	milliliter
mm	millimeter(s)
MS-222	tricaine methanesulfonate
nMDS	non-metric multidimensional scaling
NMFS	National Marine Fisheries Service
ODFW	Oregon Department of Fish Wildlife
POC	particulate organic carbon
PNNL	Pacific Northwest National Laboratory
rkm	river kilometer(s)
RME	research, monitoring, and evaluation

RPA	Reasonable and Prudent Alternative
s	second(s)
s.d.	standard deviation
SRD	Sandy River delta
TSS	total suspended sediments
USACE	U.S. Army Corps of Engineers
UW	University of Washington

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1.0 Introduction

The study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL), the Oregon Department of Fish and Wildlife (ODFW), the National Marine Fisheries Service (NMFS), and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the 2011 study was to provide site-scale pre-restoration research for the proposed rechannelization of the Sandy River delta (SRD) and to evaluate landscape-scale conditions for juvenile salmon between the confluences of the Lewis and Cowlitz rivers in the lower Columbia River. This annual report covers research conducted from May 2010 through September 2011.

1.1 Background

This research project was initiated in 2007 by the Bonneville Power Administration (BPA Project No. 2005-001-00) to investigate critical uncertainties regarding juvenile salmon ecology in shallow tidal freshwater habitats of the lower Columbia River. However, as part of the Washington Memorandum of Agreement (Washington-Action Agencies 2009), the project was transferred to the USACE in 2010. In transferring from BPA to the USACE, the focus of the tidal freshwater research project shifted from fundamental ecology toward the effectiveness of restoration in the Lower Columbia River and estuary (LCRE). With the loss and degradation of estuarine habitats and decline of salmon populations, applied research is necessary to measure the effectiveness of estuarine restoration actions and impacts on salmon populations in LCRE ecosystems.

As mitigation for operation of the Federal Columbia River Power System (FCRPS), the Action Agencies (Bonneville Power Administration and USACE) are obligated to restore juvenile salmon habitats in the LCRE under the 2008 FCRPS Biological Opinion (BiOp; NMFS 2008). The Action Agencies conduct this restoration, and associated research, monitoring, and evaluation (RME), under the Columbia Estuary Ecosystem Restoration Program (CEERP). The goal of the CEERP is to understand, conserve, and restore ecosystems in the LCRE. This study will inform the Action Agencies' 2012 CEERP Synthesis Memorandum (due June 2012). It will also contribute to meeting the requirements of BiOp's Reasonable and Prudent Alternative (RPA) actions (e.g., RPAs 59.4, 60.1, and 61.2).

The research reported here supports the CEERP by providing data pertinent to the following management question: "What are the limiting factors or threats, (i.e., stressors and controlling factors) in the estuary preventing the achievement of desired habitat or fish performance?" Answering this question provides relevant data concerning juvenile salmon density, diet, prey, genetic stock composition, and residence times; diet overlap with other fish species; and landscape-scale fish community structure. The 2010–2011 study involved pre-restoration work under the action effectiveness research RME category (Action Agencies 2012a).

As part of an ongoing study, data reported herein spans the time period May 2010 to September 2011. Previous research from 2007 through 2010 were reported on an annual basis by Sobocinski et al. (2008), Sather et al. (2009), and Johnson et al. (2011a) and can be downloaded from http://efw.bpa.gov/IntegratedFWP/reportcenter.aspx.

Key findings (excerpted from Johnson et al. 2011a) from our previous work in shallow freshwater habitats (2007–2010) of the LCRE include the following:

- Unmarked juvenile Chinook salmon were the most abundant salmonid captured (74% of the total salmonid catch), followed by chum salmon (10%), marked Chinook salmon (8%), coho salmon (8%), and steelhead trout (<1%).
- The densities of juvenile salmon were variable across all habitat types and no single habitat type consistently yielded a disproportionate number salmon.
- Genetic stock identification analyses for 1242 unmarked Chinook salmon sampled in the SRD showed a majority of the fish were from the Spring Creek Group Tule Fall (35%) and the Upper Columbia Summer/Fall (33%) stock groups. Smaller proportions were estimated for the West Cascade Tributary Fall (15%) and Willamette River Spring (8%) groups. Snake River Fall (3%), Deschutes River Fall (3%), and West Cascade Tributary Spring (2%) fish were also present.
- The total SRD catch comprised 34 species, including 18 non-native species. Total catch abundance was approximately 75% native fishes and 25% non-native fishes. Stickleback dominated the catches.
- Consistent relationships between salmon density and macro-habitat features, environmental conditions, and structural attributes were not apparent. Assuming salmon density indicates relative importance, no single or suite of macro-habitat features, environmental conditions, or structural attributes emerged as most important for juvenile salmon in shallow tidal freshwater.
- The large contribution of aquatic and terrestrial insects to the diets of juvenile salmon at the SRD sampling sites, and the generally high densities of insect prey in the benthos, drift, and fallout across seasons, indicate shallow tidal freshwater habitats may be well suited to supporting juvenile salmon rearing.
- Bioenergetics modeling showed that mean predicted specific growth rates across sampling sites for simulation cohorts were *positive* and varied little, except during sustained high temperature extremes.
- During spring and summer 2007 and 2008, a fraction (3−11%) of acoustic-tagged, run-of-river yearling and subyearling Chinook salmon and steelhead from upriver sources used off-channel and main channel pathways in the SRD and vicinity. These actively migrating fish moved quickly (a few hours) through the study area. In contrast, during winter to early spring 2010, residence time averaged 34 days for 48 juvenile Chinook salmon captured, tagged, released, and detected in the SRD. Fish tagged during the winter exhibited life history strategies different from those of the actively migrating spring/summerfish from upriver sources.

1.2 Study Objectives

The overall goal of this study is to evaluate the effectiveness of habitat restoration projects in the LCRE at both site and landscape scales.

Objectives for the 2010–2011 reporting period were as follows:

1. Perform site-specific action effectiveness research to evaluate controlling factors, ecosystem structures, and functions in the SRD and vicinity in anticipation of the rechannelization restoration, including environmental conditions, fish community composition, salmon density and lengths, genetic stock identification, and water chemistry.

1.a. Characterize diets of juvenile Chinook salmon and abundant resident fish species.

1.b. Describe compositions of prey pools in tidal freshwater habitats of the LCRE.

2. Compare fish communities, salmon catch proportions and lengths, and salmon densities at the landscape scale between two areas of the LCRE.

3. Estimate mean residence time of large (95−125 mm) salmon that are present during winter months at the SRD and in the vicinity.

The ensuing sections of this report describe the study methods and results and present conclusions and recommendations. The appendix contains a statistical plan for estimating juvenile salmon density at the landscape scale.

2.0 Methods

The study area is described first below, followed by descriptions of how the fish were captured for diet analysis, the samples collected for analysis of genetic composition, fish diet and availability of prey, characterization of water properties at the SRD sites, and investigation of the residence time of juvenile salmon in shallow tidal freshwater.

2.1 Study Area

The tidally influenced freshwater portion of the Columbia River extends from approximately Tenasillahe Island to Bonneville Dam (rkm 56–234). Sampling for our study occurred within two distinct areas of the tidal freshwater segment of the LCRE: the SRD and the LRR area (Figure 2.1). Sites at the SRD are representative of off-channel habitats, with the exception of a wetland channel at Site N, which is located in a remnant channel of the historic SRD (Figure 2.2). These sites were selected for the purposes of the Before-After-Reference-Impact (BARI) design (see below). Full descriptions of habitat characteristics for each of the SRD sites are provided by Sobocinski et al. (2008) and Sather et al. (2009).

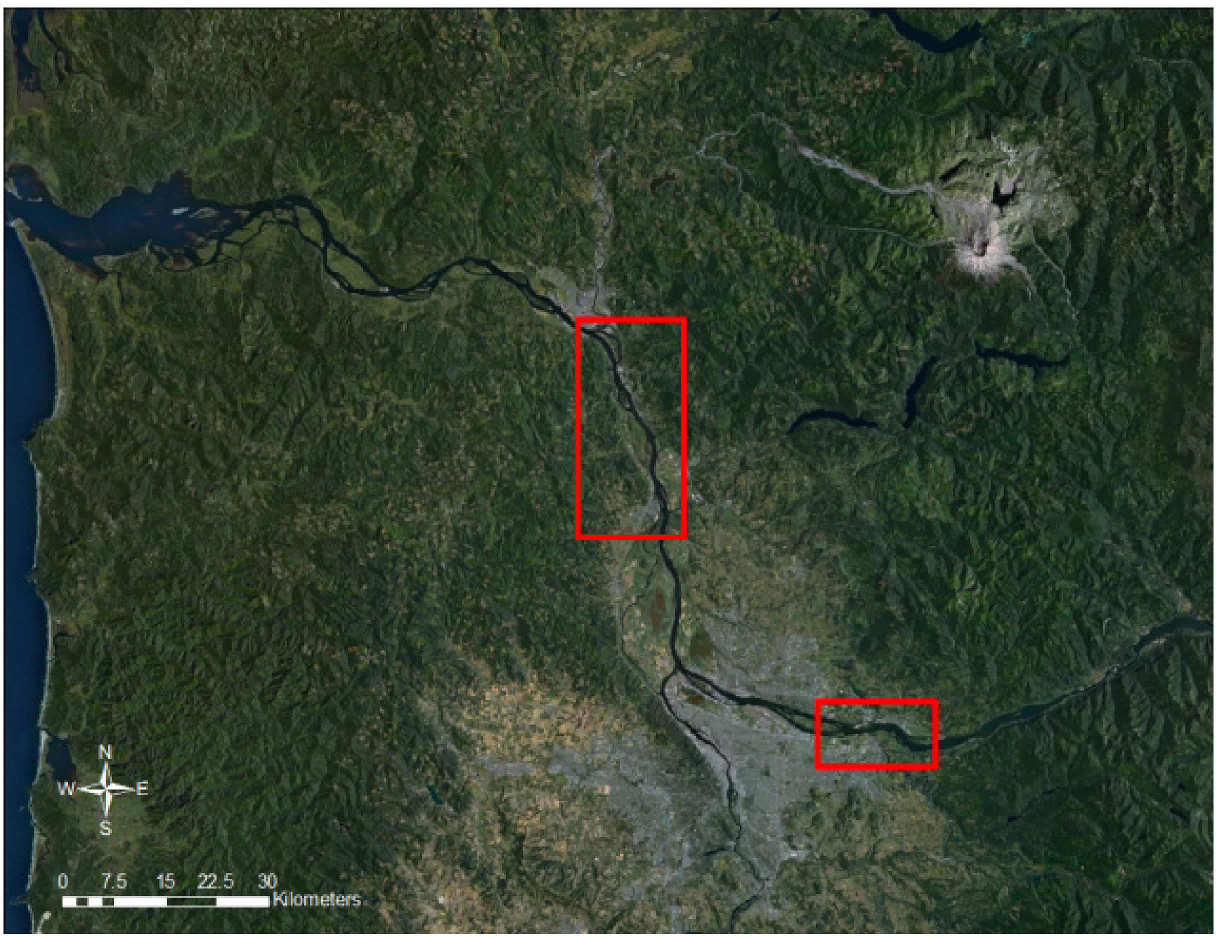

Figure 2.1. Location of the SRD (bottom rectangle; rkm 188–202) and LRR (top rectangle; rkm 110–141) study areas in the LCRE tidal freshwater.

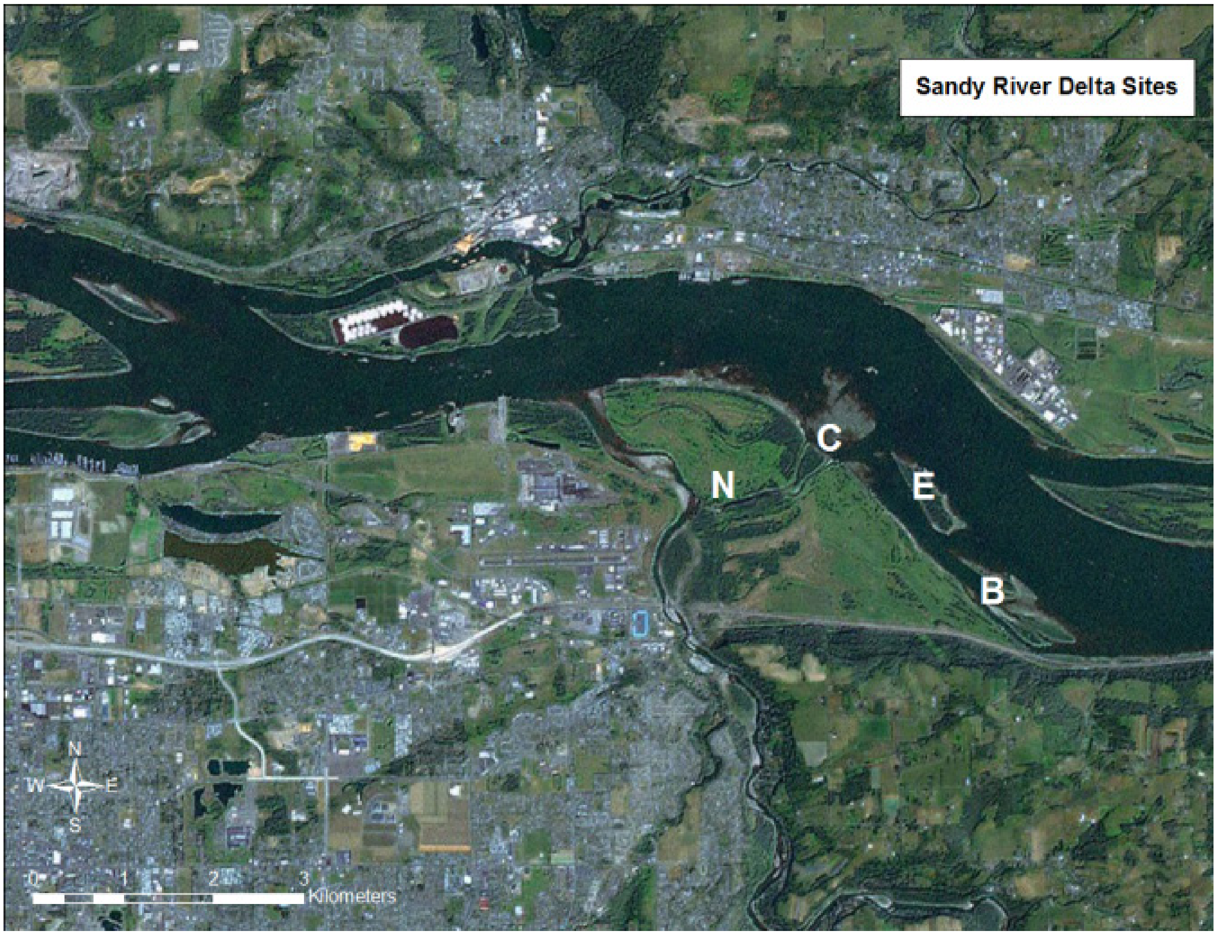

Figure 2.2. Sampling sites in the SRD study area (rkm 188–202).

2.2 Sampling Design

The SRD study area (rkm 188–202) includes four sites (Figure 2.2) that were selected as part of a BARI experiment design (Sobocinski et al. 2008). These sites were typically sampled monthly, except when high flow conditions prevented data collection efforts (e.g., May and June 2011). In addition, sampling did not occur between July 2010 and October 2010 because the project was undergoing a transitional period during transfer from BPA to the USACE (see Section 1.1, Background).

In the LRR, a random stratified sampling design was used for the purpose of estimating fish density (see appendix). Up to 15 sites were randomly sampled seasonally across three habitat strata (main channel, off channel, and wetland channel; Figure 2.3) within a rotational panel design. Details pertaining to site selection criteria are described by Sather et al. (2011). For the current reporting period, LRR sites were sampled during winter and summer 2011; high flow conditions prevented the spring 2011 sampling event.

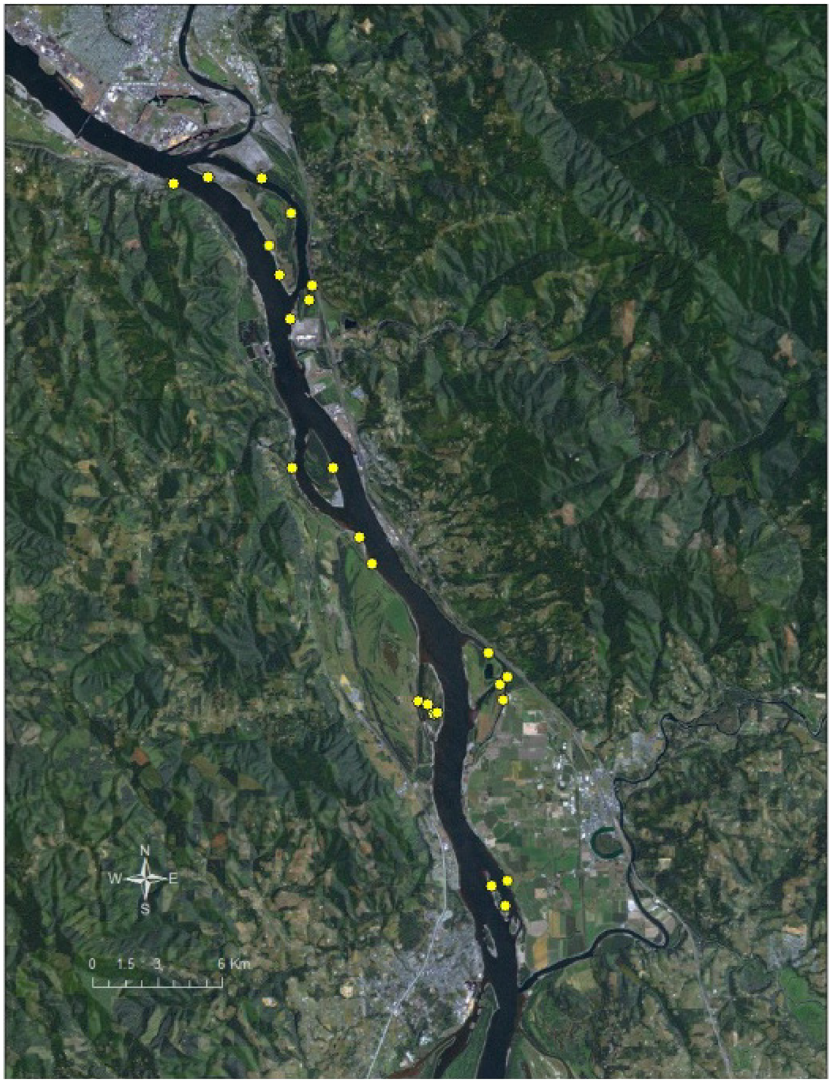

Figure 2.3. Sites sampled in the LRR during winter and summer 2011.

2.3 Fish Capture

To capture fish, we deployed either a 46-m beach seine (1.5–3 m depth; 13-mm knotless mesh wings; 3-mm knotless mesh purse; 15-m haul lines; Sites B, C, and E) or a 30.5-m beach seine (3 m depth; 5-mm knotless mesh; Site N). At Sites B, C, and E, the beach seine was set by boat except when water depths were prohibitively low or site accessibility was poor at the time of sampling; during these instances the net was deployed by foot. Due to inaccessibility by boat throughout the year and space constraints at site N, the smaller beach seine (30.5 m) was always set by foot. Two non-overlapping hauls were performed at each site with a minimum interval of 30 minutes between sets. After each haul, all salmon and steelhead were removed immediately from the net and placed in holding buckets filled with sufficiently oxygenated river water at ambient temperature. The remaining individuals (i.e., non-salmon taxa) were placed in separate holding buckets until processing. When catches were large, non-salmon fishes were subsampled according to the protocol described by Sather et al. (2011). To minimize handling stress, salmon and steelhead were anesthetized using a 40-mg/L solution of MS-222 (tricaine methanesulfonate) prior to processing.

Data pertaining to fish community characteristics have been reported using a combination of descriptive and analytical approaches. Multivariate techniques were used to examine the relationship among fish communities at the SRD and LRR study areas. For these analyses, all unidentified taxa were excluded to ensure that they were not represented twice. Bray-Curtis similarities among samples were calculated using square-root transformed densities of fish assemblages. The results of the similarity analysis were displayed in a two-dimensional (2D) non-metric multidimensional scaling (nMDS) plot. Non-parametric statistics were used to examine differences in size of Chinook salmon between the SRD and LRR study areas and between habitat types in the LRR.

2.4 Genetic Stock Composition

Samples collected for genetic mixture analysis were obtained from fin clips on a subset of juvenile Chinook salmon sampled from the SRD and LRR sites. All fin clips were preserved in ethanol until analysis. We used standard methods of genetic stock identification and individual assignment (reviewed by Manel et al. 2005). Chinook salmon were genotyped using the methods described by Teel et al. (2009). Data were collected for 13 microsatellite loci that have recently been standardized among several west coast genetics laboratories (Seeb et al. 2007). Genetic mixture analysis and the relative probability of stock origin of each sample were estimated using the genetic stock identification computer program ONCOR (Kalinowski et al. 2007). Confidence intervals of the mixture proportions were estimated using ONCOR by re-sampling the mixture and baseline data 100 times. Population baseline data were derived from the multi-laboratory standardized Chinook salmon genetic database described by Seeb et al. (2007). Mixture proportions and assignment probabilities for individual baseline populations were summed to 10 Columbia River Basin stock groups (Sather et al. 2011).

2.5 Fish Diet and Prey Availability

We collected data at four sites (B, C, E, and N; [Figure 2.2]) at the SRD from May 2010 through September 2011 to 1) characterize diets of juvenile Chinook salmon and abundant resident[1] fish species, and 2) describe compositions of specific prey pools in tidal freshwater habitats of the LCRE.

2.5.1 Field Processing

Morphometric attributes and diets of juvenile Chinook salmon were sampled monthly at each site according to procedures detailed by Storch and Sather (2011). Anesthetized fish were measured to the nearest milimeter (fork length [FL]) and weighed (nearest 0.01 g). Gastric lavage was then performed on up to 20 randomly selected fish, more than 50 mm in length, to remove stomach contents. Following lavage, samples were preserved, and salmon were allowed to recover before being released.

We also sampled the diets of non-native bluegill, pumpkinseed, and killifish, and native stickleback periodically (May 2010, June 2010, November 2010, February 2011, July 2011) at each site to evaluate diet overlap with juvenile Chinook salmon. These taxa were chosen for their potential to have large per capita competitive impacts at our sites. Resident fishes were identified and measured (FL or total length, depending on species). Up to 10 fish, $\geq$50 mm, of each taxa were weighed (nearest 0.01 g) and

[1] In this report, the term "resident" is applied to specific fish taxa encountered at our sites that are not anadromous.

dispatched according to official permitted protocols. Sacrificed fish were placed individually in labeled 100-mL polyethylene sample bottles and preserved in 70% ethanol.

To characterize community compositions of specific prey pools, on a seasonal basis (November 2010, February 2011, July 2011), we applied a combination of benthic, drift, and terrestrial/winged prey sampling methodologies as outlined by Storch and Sather (2011). At all sites, duplicate samples from each prey pool were collected and preserved. Benthos was sampled at two points parallel to the shore using a standard Ekman dredge (232 cm^2). Drifting invertebrates were sampled with plankton nets (363-μm mesh) placed 3–6 m from the waterline, midway in the water column, and facing upstream. Nets were set for approximately 24 hours and, when possible, instantaneous flow readings were recorded near the mouth of each net at both the beginning and the end of sampling periods. Terrestrial or winged organisms were sampled using floating fallout traps (0.2 m^2) filled with a solution of filtered river water and liquid surfactant. Traps were set for 48 hours and positioned downstream of the drift nets.

2.5.2 Laboratory Procedures

To extract stomach contents from euthanized resident bluegill, pumpkinseed, killifish, and stickleback, we first removed and dissected the anterior digestive tracts (i.e., excluding the intestine). Prey items from each fish were then rinsed into individual sample containers and preserved with 70% ethanol until later analysis. Stomach contents from both juvenile Chinook salmon and resident fish were further processed to quantify diet composition by both number and biomass. To this end, prey items in diet samples were identified to the lowest classification practicable using standard taxonomic keys (e.g., Merritt and Cummins 1996), then counted and preserved in individual centrifuge vials according to taxon and life history stage. Consumed biomass was quantified by weighing whole animals (blotted dry; nearest 0.001 g), either individually or as a group, depending on size.

As in diet samples, organisms in prey community samples were identified to the lowest feasible taxonomic resolution. Whenever possible, we enumerated entire samples, but when prey densities were appreciably large, we subsampled according to accepted protocols. Benthos was subsampled following methods adapted from Boward and Friedman (2000). For each benthic sample, randomly selected subsamples (i.e., fractions of the entire sample partitioned using a gridded tray) were enumerated successively until 120 organisms were counted or the entire sample had been processed. Organisms encountered in both drift and fallout samples were subsampled, when necessary, using standard procedures (Mills et al. 1992; Storch et al. 2007). Total sample counts were extrapolated from subsamples following relationships described by Storch and Sather (2011).

We estimated densities of taxa in the environment using methodologies applied previously (Storch and Sather 2011). For benthos, prey densities ($\#/m^2$) were calculated by dividing sample counts by the area of the dredge opening. To estimate densities of drifting prey, the total volume of water flowing through each plankton net was approximated using hydrographs for the lower Columbia River, recorded over the respective sampling periods, and adjusted to beginning and end instantaneous flow measurements. Sample counts were then divided by the total volume of water flowing through each net to arrive at final total densities ($\#/m^3$). Densities of terrestrial and/or winged prey were calculated by dividing fallout sample counts by both the area of the fallout trap and the sampling time ($\#/m^2/hr$).

2.5.3 Diet Data Analysis

2.5.3.1 Relative Importance

The Index of Relative Importance (IRI; Pinkas et al. 1971) is a compound model combining information about a consumer's diet in terms of number, biomass, and frequency. To assess the importance of specific prey items in Chinook salmon diet, we calculated IRI values by averaging the numbers and biomasses of individual prey found in gut contents during each site-sampling period when fish were captured (hereafter, sampling episode) and then calculating a single composite score (Storch et al. 2007). These IRI scores were then standardized (%IRI) to fall within a discrete scale (i.e., 0–100%; Cortés 1997) allowing for direct comparisons among different food types. Further details of IRI calculations are presented by Storch and Sather (2011).

2.5.3.2 Prey Selection

To characterize the foraging behavior of juvenile Chinook salmon at our sites, we used the same stepwise approach described by Storch and Sather (2011), where 1) selectivity coefficients (W_i; Vanderploeg and Scavia 1979a) were calculated to summarize the relative proportion of prey items within a particular site in relation to the proportion of those prey items within the diets, and then 2) W_i values were standardized using the Relativized Electivity Index (E_i*;Vanderploeg and Scavia 1979b) to portray the degree to which Chinook salmon were selecting or avoiding a particular prey item. Similar to %IRI calculations, single electivity coefficients were calculated by averaging numbers of individual prey found in gut contents during each sampling episode to represent generalized foraging behavior.

Electivity index values were calculated for each of the three potential prey sources sampled: benthos, drift, and fallout (i.e., terrestrial or winged prey). To achieve this, based on the life stage of prey items and/or knowledge of its general behavior, diet data were coded according to where in the environment a particular prey item was most likely to be encountered by a juvenile salmon. For example, although it is possible that a predator could encounter *Daphnia* spp. in the benthos, because the crustacean is planktonic, the likelihood is greater that the invertebrate would be consumed in the drift.

Many prey items encountered in gut content samples could not be easily associated with a specific source habitat. To account for uncertainty associated with prey taxa that could have been encountered by a fish either in the benthos or the drift (hereafter termed "ambiguous" taxa), the electivity model was applied to gut content data matrices where 1) 50% of ambiguous prey were attributed to foraging in the drift, 2) 50% of ambiguous prey were attributed to foraging in the benthos, 3) 100% of ambiguous prey were attributed to foraging in the drift, and 4) 100% of ambiguous prey were attributed to foraging in the benthos.

2.5.3.3 Diet Overlap

To inform inferences regarding potential for intra-specific competition in different tidal freshwater habitats in the SRD, we examined the diet overlap between juvenile Chinook salmon and resident species (bluegill, pumpkinseed, killifish, and stickleback) using the Schoener Index (Eq. (2.1); Schoener 1970).

$$C_{xy} = 1 - 0.5(\sum_{i=1}^{n} |p_{xi} - p_{yi}|) \qquad (2.1)$$

where p_{xi} is the proportion (by mass) of food type (prey taxon) i used by species x, and p_{yi} is the proportion (by mass) of food type (prey taxon) i used by species y.

This measure of diet overlap incorporates both relative occurrence and contribution to total food volume (biomass) by a prey taxon, thus limiting potential distortions caused by abundant small or scarce large prey items (Wallace 1981). The Schoener Index results in values ranging from 0 to 1, where 0 represents no overlap between species, and 1 represents full overlap (Schoener 1970; Wallace 1981). Index values greater than or equal to 0.60 can be considered biologically significant (Zaret and Rand 1971; Mathur 1977). The Schoener Index was selected due to its broad use in fisheries research, which includes other studies focused on juvenile salmon (Fisher and Pearcy 1997; Auburn and Ignell 2000).

2.6 Water Properties

During the past year, a task was initiated to begin to characterize a suite of physical and biogeochemical properties (e.g., nutrients and organic matter) in the water column at each of the four SRD sites in association with prey availability sampling. The recent Independent Scientific Advisory Board (ISAB 2011) report on Columbia River food webs noted knowledge and data gaps with respect to the base of the food web, including nutrients and organic matter, and further recommended data gathering and synthesis with respect to components where "our base-level understanding of the Basin's food webs remains rudimentary." In response to ISAB recommendations above, and as part of this project's shift in focus toward action effectiveness research, we collected water property data to add to a body of knowledge that will help determine site-scale responses before and after restoration actions. The suite of water property data collected (i.e., temperature, dissolved oxygen [DO], total suspended sediments (TSS), particulate organic carbon (POC), chlorophyll-*a*, and nutrients) is an initial characterization of physical and biogeochemical attributes.

Water property samples were collected from SRD at Sites B, C, E, and N in conjunction with prey availability and beach seining efforts. Samples were collected during fall, winter, and summer months (e.g., November 2010, and February, July, and November 2011). In general, the field and laboratory methods were similar to those of Woodruff et al. (2011) with some exceptions. Two samples per site were collected (duplicates) during the November 2010 field trip, and thereafter only one sample per site plus one field duplicate was collected. Sampling was conducted in the immediate vicinity of prey collection and/or beach seining, while minimizing disturbance between collection activities. Water property samples were measured or collected near the surface and bulk water was collected for processing of nutrients, organic matter, and suspended sediments. Samples were processed to the extent possible in the field, placed on ice, and further processed following methods reported by Woodruff et al. (2011). All samples were analyzed at the Pacific Northwest National Laboratory's Marine Sciences Laboratory or the UW. Table 2.1 provides details about the sampling scheme and methods used for collection and analysis.

Table 2.1. Summary of surface water property parameters and sampling and analysis scheme at Sites B, C, E, and N.

Parameter	Field Method	Laboratory Method
Temperature (°C)	YSI Model 556 Handheld Sonde	NA
Salinity (psu)		
DO (mg/L)		
Chlorophyll *a* (μg/L)	Surface Grab Sample	Welschmeyer (1994)
POC (mg C/L)		Sugimura and Suzuki (1988)
TSS (mg/L)		APHA Standard Methods 2540
PO_4-P (μg/L)		Bernhardt and Wilhelms (1967)
NO_3-N (μg/L)		Armstrong et al. (1967)
TN (μg/L)		Valderamma (1981)

APHA = American Public Health Association; DO = dissolved oxygen; POC = particulate organic carbon; TSS = total suspended sediments; PO_4–P = phosphate as phosphorus; NO_3-N = nitrate as nitrogen; TN = total nitrogen; NA = not applicable; psu = practical salinity units.

Data were summarized using descriptive statistics and were further explored using a multivariate approach. nMDS was used to evaluate similarities and differences in water properties within and between sites for multiple dates. Pair-wise correlations and similarity, based on the Euclidean distance of standardized variables, were calculated. The similarity results are shown in a 2D nMDS ordination plot that iteratively arranges observations in space until the distance between observations agree with their similarity, as measured by a stress statistic.

2.7 Residence Time Study

The residence time of juvenile salmon in shallow tidal freshwater habitats of the LCRE is largely unknown. Such knowledge is important to CEERP managers because it indicates the importance of these habitats to juvenile salmon, including those listed under the Endangered Species Act of 1973. In 2010, residence times for juvenile Chinook salmon that were captured and tagged during winter in the SRD vicinity averaged 34 d with a median of 26 d and a range from 1 to 78 d (Johnson et al. 2011b). The 2011 study was intended to corroborate the results of the 2010 study. The objective of the 2011 study was to estimate the residence times of juvenile salmon during winter 2011 in the area behind Gary Island near the SRD.

Acoustic transmitters (Juvenile Salmon Acoustic Telemetry System; manufactured by Sonic Concepts) were surgically implanted in 50 juvenile salmon captured with a beach seine (see Sather et al. 2011). The acoustic tag weight was 0.63 g (in air). The mean size of salmon tagged was 116 mm FL and 16 g. All but one of the tagged fish was unmarked (i.e., no adipose fin clip, passive integrated transponder tag, or coded wire tag). Post-surgery survival was 96% with 49 fish surviving the 24-h holding period prior to release. Fish were released behind Gary Island from February 3 through February 16, 2011. Five autonomous acoustic nodes were placed in the off-channel area behind Gary and Flag islands, as in 2010 (Johnson et al. 2011b), to detect signals from the transmitters in the tagged fish. The receiving nodes were in place from February through early May 2011. A concurrent tag-life study in a tank at PNNL offices in North Bonneville showed tag life was more than 90 d with the pulse repetition interval of 10 s used in the study. This finding indicates no effect of transmitter battery life on final detection events and residence times. One tagged fish was still present in the study area when the nodes were removed and, therefore, could not be used in the analysis. A total of 48 tagged fish composed the residence time data set. Methodologies associated with analysis of residence time data are available from Johnson et al. (2011b). The residence time investigation has the following assumptions and caveats:

- The residence time estimates are conservative because we do not know how long a given fish was in the study area before it was captured and tagged.
- Tagged fish behavior is not affected by the tag; i.e., tagged fish are representative of untagged fish.
- The date/time of last detection on a receiving node indicates when fish left the study area.
- The tagged fish have not been eaten.

3.0 Results

Results derived from work spanning the May 2010 to September 2011 time period describe a combination of environmental and biotic attributes. Results pertaining to site-scale (i.e., SRD) action effectiveness research are reported first. Data relevant to pre-restoration research include controlling factors (water level and temperature), fish community characteristics, genetic stock identification of salmon, elements of food web interactions, water chemistry, and residence time of salmonids. Results then transition to findings relevant to the landscape-scale objective, which is based on seasonal sampling of fish communities over a broad spatial expanse within the tidal freshwater portion of the LCRE.

3.1 Sandy River Delta

Results for the SRD describe environmental conditions, the composition of the fish community, juvenile Chinook salmon density and length, identification of Chinook salmon genetic stock composition. The diet of juvenile Chinook salmon and the relative importance of prey and prey electivity are also described and are followed by an analysis of diet overlap between species. Lastly, attributes of water chemistry are provided.

3.1.1 Environmental Conditions

The shallow water habitats sampled as part of this study were influenced by the seasonal fluctuation in river discharge. While inter-annual variability affects the timing and magnitude of discharge, general seasonal patterns in the LCRE were such that relatively low flow conditions persisted from late summer through fall and peak discharge occurred during mid-spring to early summer months (Figure 3.1). Discharge during 2011 yielded high flow conditions throughout much of the spring-summer months.

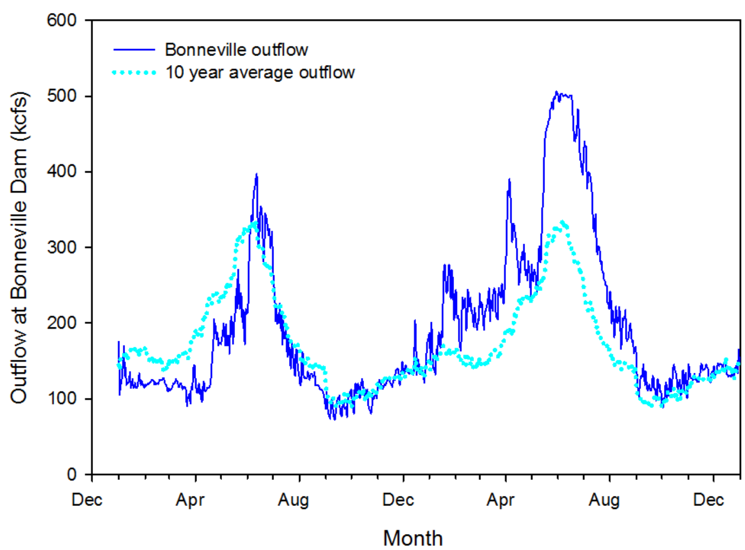

Figure 3.1. Daily average total discharge (kcfs) measured at Bonneville Dam, January 2010–December 2011. The 10-year average outflow (2002–2011) is displayed as the dotted light blue line (data from Columbia River Data Access in Real Time [DART] 2011).

Seasonally, the four SRD sites were generally similar to each other in terms of water elevation and temperature (Figure 3.2). The patterns observed across site-scales emulated seasonal patterns in river discharge. However, within a given season, variability in both water-surface elevation and water temperature was observed among the four SRD sites, especially when river discharge was low. The degree to which sites respond to river conditions is linked to a site's relative position from the main channel, as indicated by the seasonal pattern of water-surface elevation and temperature at Site N, the furthest removed of the four sites. Site N was different from conditions observed at the other three sites due to the relative lack of hydraulic connectivity.

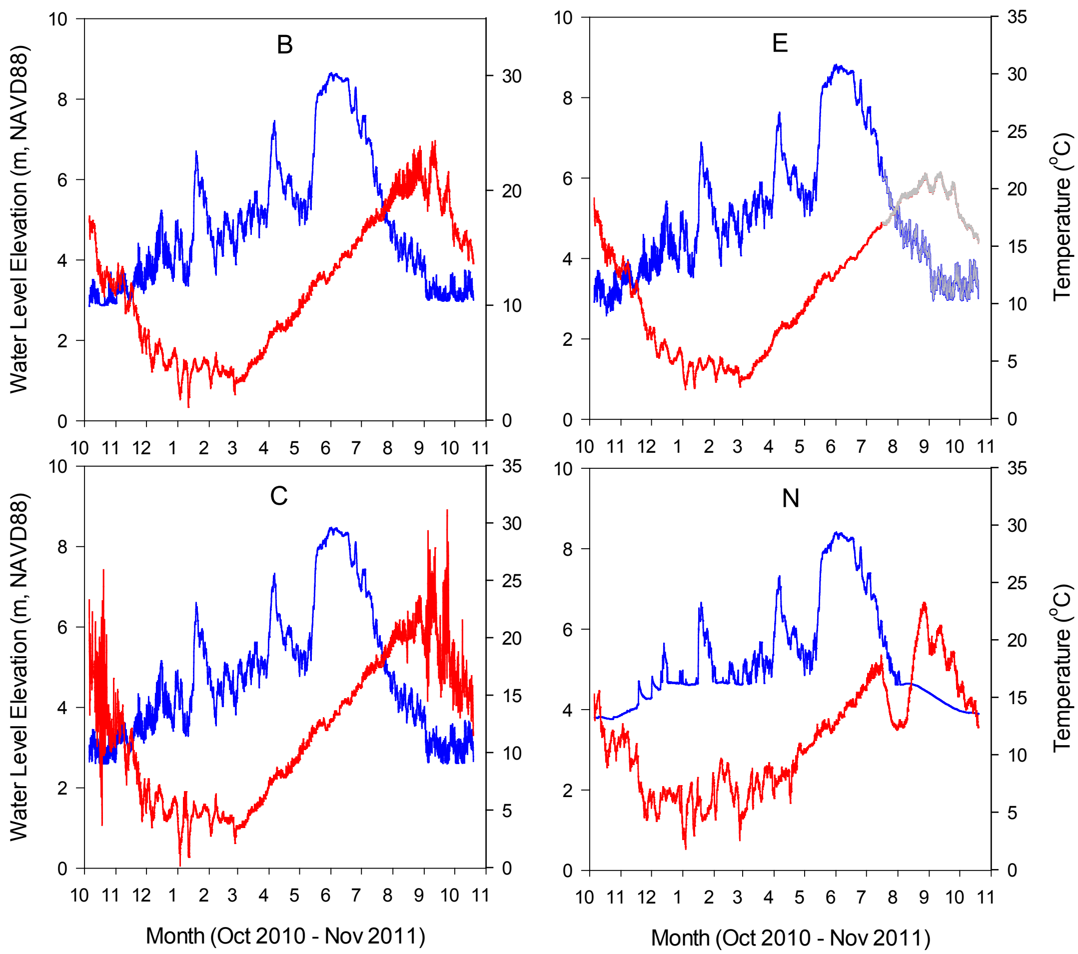

Figure 3.2. Water-surface elevation (blue) and water temperature (red) from Hobo data loggers at Sites B, C, E, and N at the SRD. The Hobo sensor at Site E was discovered to have moved from its installation location and been buried in sediment on July 17, 2011; displayed in gray. Therefore, data following this time period should be considered uncorrected.

3.1.2 Fish Community Composition

Total catch at the SRD from May 2010 to September 2011 consisted of 26 species, of which 13 were non-native fishes (Table 3.1). In terms of total numbers of fish captured, catches predominantly comprised native taxa, but non-native constituents accounted for approximately 21% of the total catch. Two species, threespine stickleback (*Gasterosteus aculeatus*) and banded killifish (*Fundulus diaphanous*), accounted for 82% of the total number caught.

Table 3.1. Percentage of total catch for fish captured at the Sandy River delta sites. Catches were based on sampling efforts spanning May 2010–September 2011.

Scientific Name	Family Name	Common Name	Status	% of Total Catch
Gasterosteus aculeatus	Gasterosteidae	threespine stickleback	Native	62
Fundulus diaphanus	Catostomidae	banded killifish	Non-native	20
Mylocheilus caurinus	Cyprinidae	peamouth chub	Native	7
Ptychocheilus oregonensis	Cyprinidae	Northern pikeminnow	Native	4
Catostomus spp.	Catostomidae	unidentified sucker	Native	2
Cottus spp.	Cottidae	unidentified cottid	Native	1
Richardsonius balteatus	Cyprinidae	redside shiner	Native	1
Oncorhynchus tshawytscha	Salmonidae	Chinook salmon	Native	1
Lepomis macrochirus	Centrarchidae	bluegill	Non-native	0.4
Oncorhynchus tshawytscha	Salmonidae	hatchery Chinook salmon	Native	0.2
Lepomis gibbosus	Centrarchidae	pumpkinseed	Non-native	0.1
Lepomis spp.	Centrarchidae	unidentified sunfish	Non-native	0.1
Cyprinidae	Cyprinidae	unidentified minnow	Native	0.1
Catostomus macrocheilus	Catostomidae	largescale sucker	Native	0.1
Oncorhynchus kisutch	Salmonidae	coho salmon	Native	0.1
Perca flavescens	Percidae	yellow perch	Non-native	0.1
Micropterus dolomieu	Centrarchidae	smallmouth bass	Non-native	0.1
Oncorhynchus keta	Salmonidae	chum salmon	Native	0.1
Rhinogobius brunneus	Gobiidae	Amur goby	Non-native	0.04
Alosa sapidissima	Clupeidae	American shad	Non-native	0.03
Percopsis transmontana	Percopsidae	sandroller	Native	0.03
Rhinichthys spp.	Cyprinidae	dace	Native	0.02
Cyprinus carpio	Cyprinidae	common carp	Non-native	0.01
Prosopium williamsoni	Salmonidae	mountain whitefish	Native	0.01
Cottus asper	Cottidae	prickly sculpin	Native	0.005
Platichthys stellatus	Pleuronectidae	starry flounder	Native	0.005
Micropterus salmoides	Centrarchidae	largemouth bass	Non-native	0.005
Notemigonus crysoleucas	Cyprinidae	golden shiner	Non-native	0.004
Oncorhynchus kisutch	Salmonidae	hatchery coho salmon	Native	0.003
Pomoxis annularis	Centrarchidae	white crappie	Non-native	0.003
Ameiurus nebulosus	Ictaluridae	brown bullhead	Non-native	0.002
Carassius auratus	Cyprinidae	goldfish	Non-native	0.002
Oncorhynchus mykiss	Salmonidae	steelhead trout	Native	0.001
Lampetra spp.	Petromyzontidae	unidentified Lamprey	Native	0.001

Summer 2011 yielded the highest densities (0.19 fish/m^2) for native taxa (excluding salmon) while salmon were most predominant during spring 2010 and 2011 months (Figure 3.3). Peak densities for non-native taxa (0.11 fish/m^2) were observed during fall 2010. Winter 2011 yielded the lowest densities for all groups of fish sampled at the SRD.

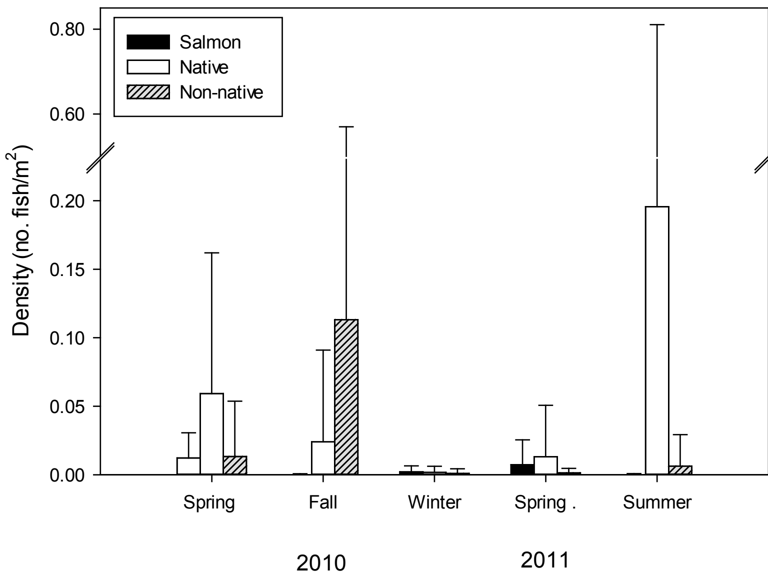

Figure 3.3. Mean density for salmon, native (excluding salmon), and non-native taxa at all SRD sites during the sample period from spring 2010 through summer 2011. Error bars represent one standard deviation.

3.1.3 Salmon Density

Four species of salmon and trout, unmarked and marked, were captured at the SRD sites during the May 2010–September 2011 time period (Figure 3.4). Unmarked Chinook salmon (Figure 3.5) and unmarked coho salmon were captured during every season, but unmarked Chinook salmon were the most abundant salmon species captured at the SRD sites. Hatchery coho and steelhead were the most infrequently captured taxa. Lowest salmon densities at the SRD occurred during fall.

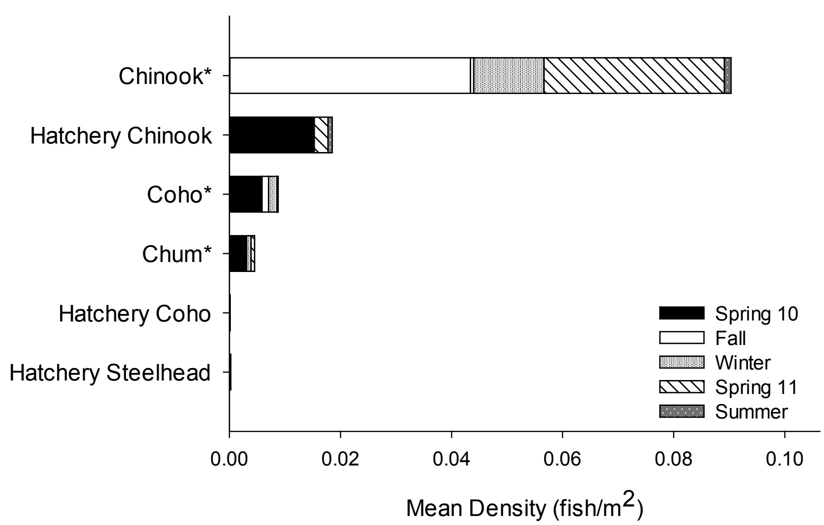

Figure 3.4. Mean density for salmonids at all SRD sites during the sampling period from spring 2010 through summer 2011. An asterisk (*) denotes fish were unmarked. Sampling spanned from spring 2010 through fall 2011; therefore, spring 2010 and spring 2011 are distinguished on the figure.

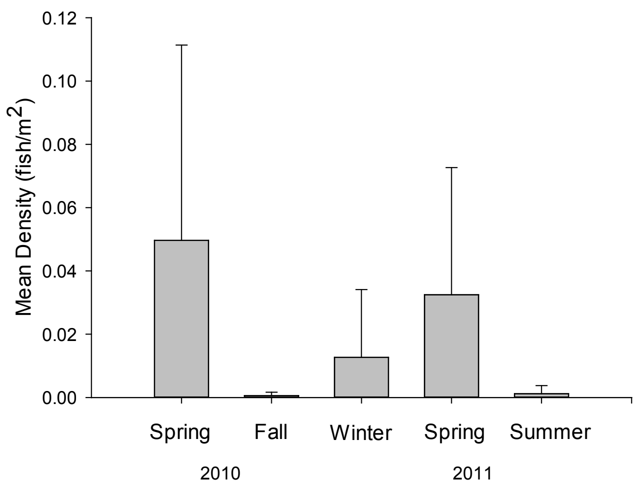

Figure 3.5. Mean seasonal density of unmarked chinook salmon sampled at the SRD during the sampling period from spring 2010 through summer 2011. Error bars represent one standard deviation.

3.1.4 Salmon Lengths

Sizes for all salmonids captured during our study period ranged from 35 to 185 mm FL, but species-specific sizes spanned narrower ranges (Table 3.2). Chum salmon were the smallest salmonids (mean 57 mm) sampled during our study period followed by unmarked Chinook salmon (mean 62 mm). Hatchery coho salmon and hatchery steelhead were the largest in size (mean 137 and 185 mm, respectively), although catches of these species were lower compared to the other species sampled.

Table 3.2. Size summary for salmonid species captured in the SRD study area during the 2010–2011 period. Sizes are expressed as fork lengths (mm). Marked salmon were those without adipose fins and/or with coded wire tags.

Taxon	Common name	Median	Mean	Min	Max	Std. Deviation	N
Oncorhynchus keta	Chum	60	57	35	74	12	53
Oncorhynchus tshawytscha	Chinook	58	62	34	141	22	520
Oncorhynchus tshawytscha	Chinook (hatchery)	82	86	51	179	20	162
Oncorhynchus kisutch	Coho	89	87	41	136	29	138
Oncorhynchus kisutch	Coho (hatchery)	137	137	134	140	4	2
Oncorhynchus mykiss	Steelhead (hatchery)	185	185	185	185	--	1

The patterns associated with length frequency distributions of unmarked Chinook salmon captured in shallow water habitats indicated distinct temporal trends (Figure 3.6). During winter months, unmarked Chinook salmon occupied two size-class groups that are indicative of different life stages. Spring months corresponded to times in which small size classes (<100 mm) are present. Following the occurrence of small sizes of unmarked Chinook during the spring months, the overall sizes of unmarked Chinook salmon sampled at the SRD increased during summer and fall months.

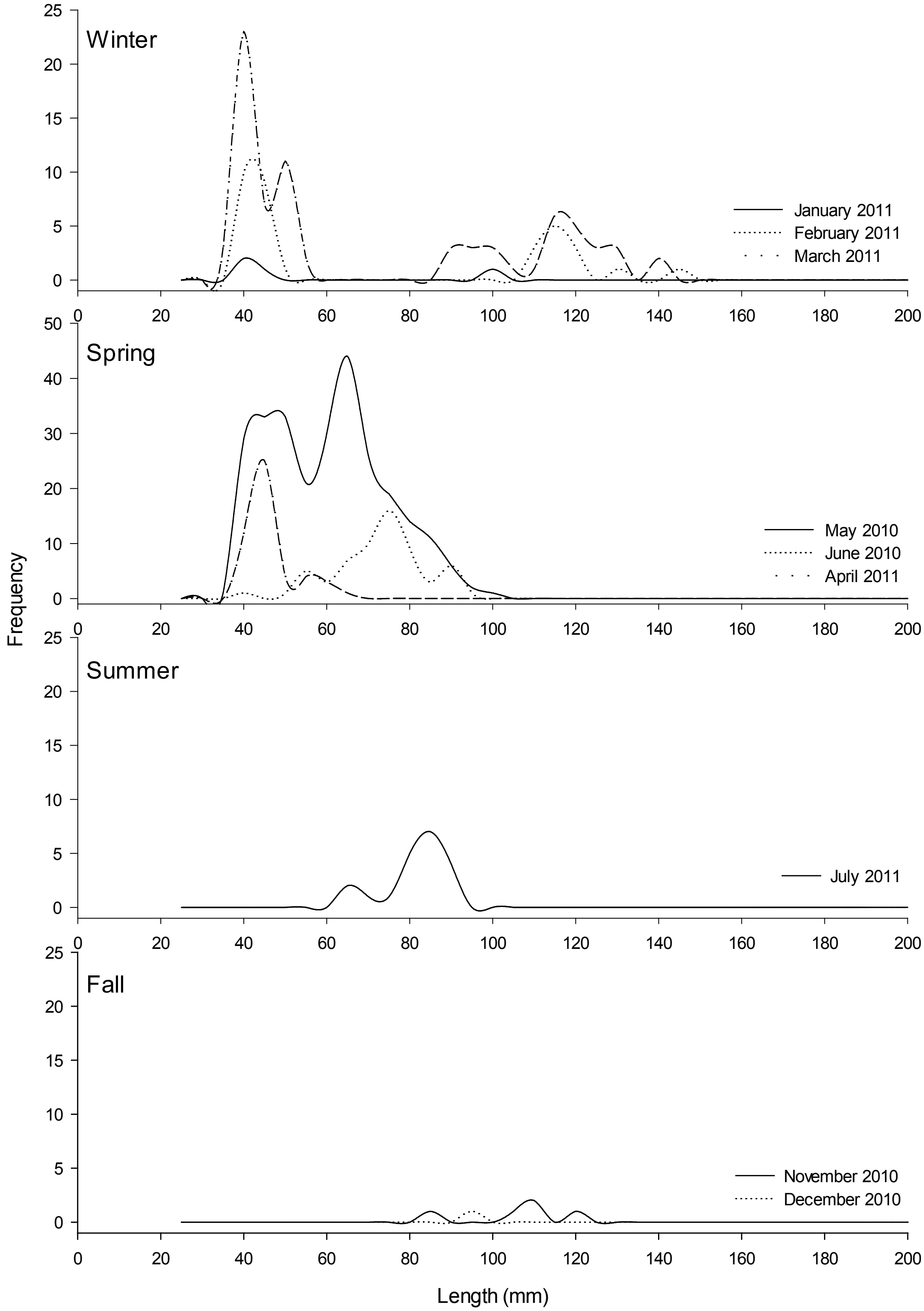

Figure 3.6. Seasonal length frequency distribution for unmarked Chinook salmon sampled at the SRD study area between May 2010 and September 2011.

3.1.5 Genetic Stock Identification: SRD

A total of 670 Chinook salmon were genotyped at 7 or more of the 13 microsatellite loci to use in genetic stock identification analysis. Stock composition estimates from the analysis of 282 unmarked Chinook salmon sampled at the SRD are presented in Table 3.3. Most of the fish were from the Upper Columbia Summer/Fall (35%) and the Spring Creek Group Tule Fall (31%) stock groups. Smaller proportions were estimated for the Willamette River Spring (15%) and West Cascade Tributary Fall (7%) groups. Deschutes River Fall (6%), West Cascade Tributary Spring (3%), and Snake River Fall (2%) fish were also sampled. A total of 50 marked (known hatchery origin) Chinook salmon captured in the SRD were analyzed genetically (Table 3.4). Most of the hatchery fish were also from the Spring Creek Group Tule Fall (49%) and Upper Columbia Summer/Fall (35%) stock groups. Four other stock groups contributed small proportions to the marked fish mixture (2%–4%). Of seven marked juveniles sampled at SRD Site B in April 2011, three yearling-sized fish were estimated with high probabilities to be spring Chinook salmon. These yearlings were from the Snake River (P = 1.0, 157 mm), Mid and Upper Columbia River (P = 0.99, 147 mm), and West Cascade (P = 1.0, 179 mm) stocks.

Table 3.3. Estimated percentage genetic stock group composition and 95% confidence intervals of 282 unmarked juvenile Chinook salmon at SRD sites from May 2010 through July 2011.

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	34.9	26.4	41.4
West Cascade Tributary Fall	6.8	4.1	13.9
Spring Creek Group Tule Fall	31.2	25.0	36.7
Snake River Fall	2.1	0.0	6.6
Willamette River Spring	15.3	9.6	19.4
Deschutes River Fall	5.8	2.5	10.0
West Cascade Tributary Spring	3.4	1.0	6.3
Mid and Upper Columbia River Spring	0.0	0.0	0.1
Snake River Spring	0.3	0.0	1.1
Rogue River	0.3	0.0	1.7

Table 3.4. Estimated percentage genetic stock group composition and 95% confidence intervals of 50 marked hatchery juvenile Chinook salmon sampled at SRD sites from May 2010 through July 2011.

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	35.1	16.4	43.3
West Cascade Tributary Fall	1.8	0.0	11.2
Spring Creek Group Tule Fall	49.0	31.4	58.8
Snake River Fall	1.9	0.0	14.3
Willamette River Spring	1.6	0.0	5.6
Deschutes River Fall	0.1	0.0	10.7
West Cascade Tributary Spring	0.4	0.0	11.7
Mid and Upper Columbia River Spring	2.0	0.0	11.7
Snake River Spring	2.0	0.0	7.4
Rogue River	1.5	0.0	5.2

3.1.6 Chinook Salmon Feeding and Prey Availability

3.1.6.1 Diet Composition

Despite considerable variability in both space and time, the diets of juvenile Chinook salmon sampled at our sites from May 2010 through September 2011 generally were dominated by five groups: dipterans (primarily chironomids and ceratopogonids), cladocerans (largely bosminids), amphipods, odonates, and hemipterans. Of these taxa, dipterans most frequently constituted large proportions of gut content biomass, accounting for more than 20% of Chinook salmon diet during 11 of 21 (52%) sampling episodes in which non-empty gut content samples were collected. During May of 2010, cladocerans accounted for a large majority of consumed biomass at each site (0.87–0.97), but the crustaceans generally were absent from diet samples throughout the remainder of the study period. Although no other individual insect taxon contributed to the diets of juvenile Chinook salmon to the same extent as dipterans, at times members of Hemiptera and Odonata combined to constitute large proportions of the gut content biomass (>20% of the diet during 24% of sampling episodes; Figure 3.7).

Appreciable diet proportions (0.24–0.90) of the group consisting of other non-dipteran aquatic insects (i.e., coleopterans, ephemeropterans, hymenopterans, plecopterans, and trichopterans) were encountered at Sites E and C, but were restricted to few sampling months. Crustaceans belonging to "Other Crustacea" (primarily Copepoda and Mysidae) and fish periodically were also well represented (each accounting for >20% of the diet in approximately 10% of sampling episodes), constituting maximum proportions of 0.44 and 0.93, respectively. The largest combined biomass proportions of prey items included in the "Other" category (i.e., Animalia, Annelida, Arthropoda, Bryozoa, Cnidaria, eggs, Isopoda, Mollusca, Nemata, plant material, fish scales), were encountered during spring or early summer months, with the maximum proportion occurring at Site C (0.15). Terrestrial invertebrates (e.g., Arachnida) were relatively uncommon in diet samples, on average, never exceeding 5% of consumed prey biomass during any sampling episode. Those insects that could not be identified beyond class (i.e., "Unidentified Insecta") due to degradation resulting from digestive processes occurred infrequently in diet samples, and only at Site E during June 2010 did the invertebrates account for a notable (0.17) proportion of gut content biomass (Figure 3.7).

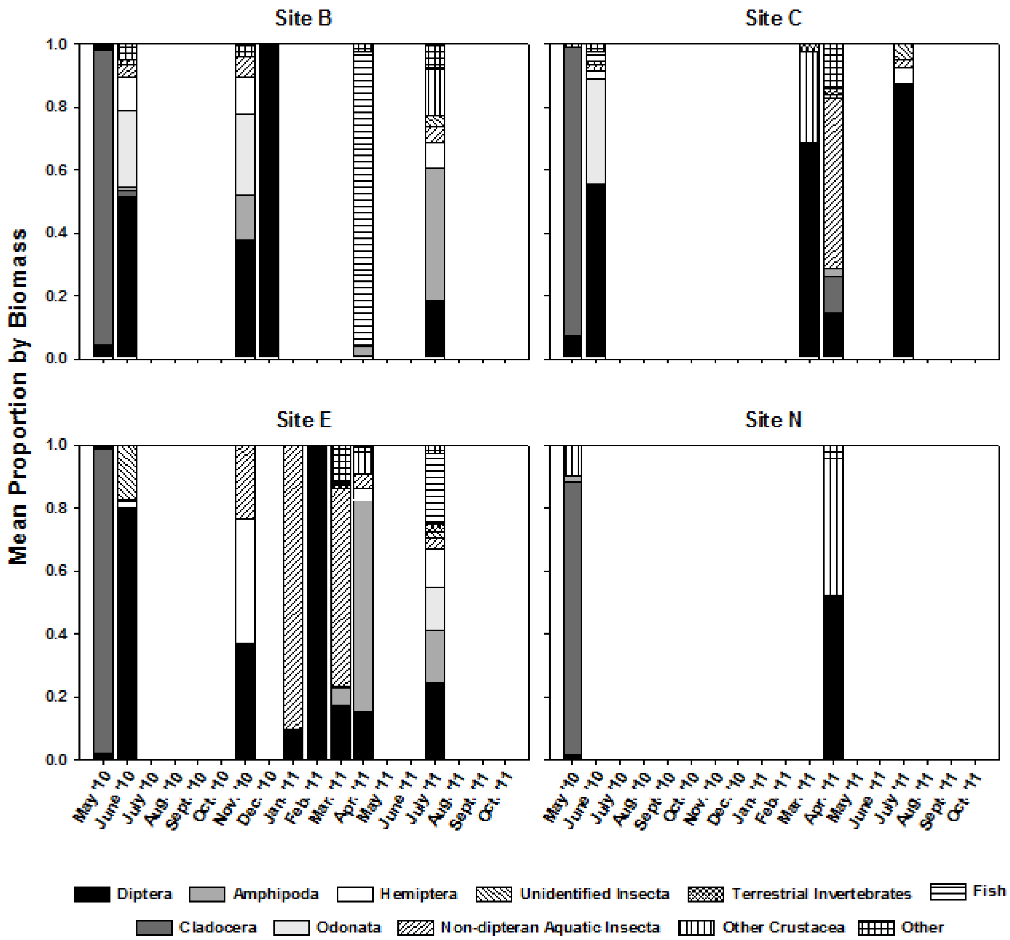

Figure 3.7. Distribution of biomass proportions of major prey categories found in the gut contents of Chinook salmon. Missing data indicate episodes in which sampling was not conducted or no Chinook salmon of a size appropriate for gastric lavage were encountered.

3.1.6.2 Relative Importance of Prey

Trends in %IRI for taxa associated with weighted mean values ≥10% (see Storch and Sather 2011 for explanation) were similar to those described by biomass proportions (c.f., Figure 3.7 and Figure 3.8). Dipterans, amphipods, and cladocerans were generally the most important prey taxa, with combined %IRI values greater than 50% during a majority (86%) of sampling episodes. Of these taxa, Diptera was most commonly associated with the greatest %IRI scores (14 of 21 sampling episodes), exceeding 50% during 52% of all sampling episodes in which non-empty gut content samples were collected (mean %IRI = 52.69% ± 35.57 s.d.; range = 0.6% − 100.0%; Figure 3.8).

Unlike dipterans, the remaining two taxa (amphipods and cladocerans) were periodically associated with large %IRI values. Cladocerans appeared to be particularly important in the diets of juvenile Chinook salmon at our sites during May of 2010 (mean %IRI = 93.27% ± 5.34 s.d.; range = 85.7% –97.6%). However, with one exception (Site C during April of 2011, %IRI = 26.38%), %IRI scores calculated for these crustaceans were less than 1% across all other sampling episodes. High %IRI scores for amphipods appeared to be unrelated to sampling episode and the maximum %IRI score (70.60%) was considerably lower than the largest values calculated for cladocerans (Figure 3.8).

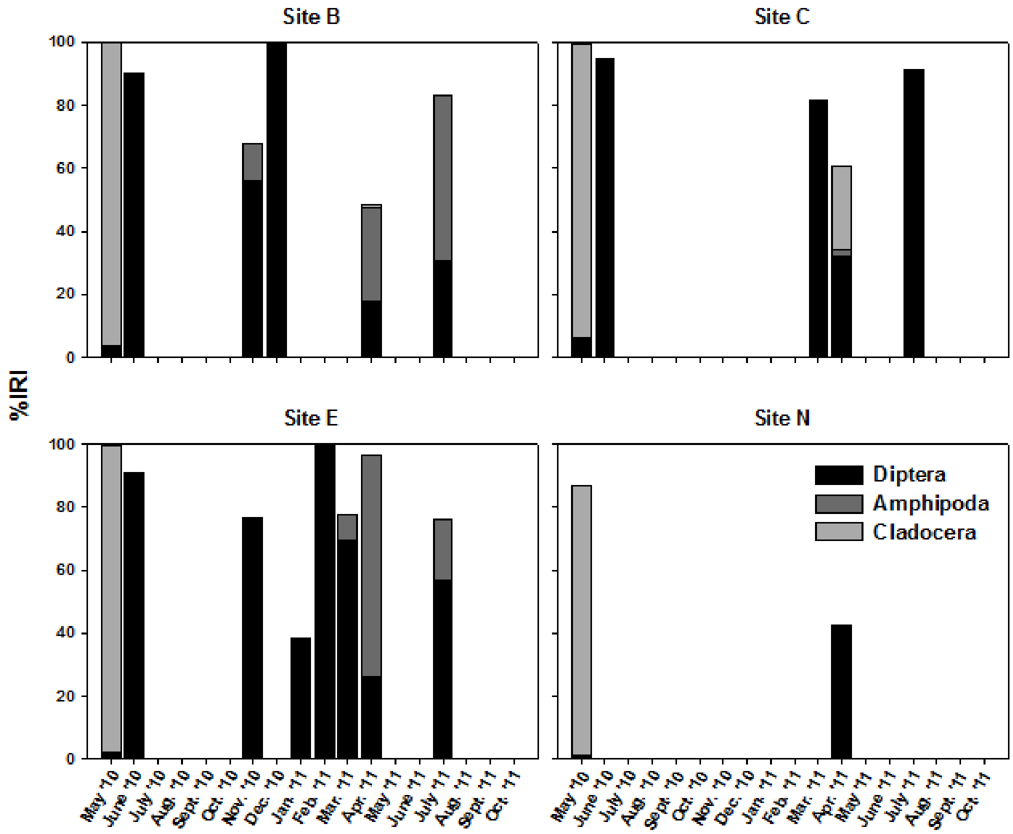

Figure 3.8. Distribution of %IRI values for major prey categories found in the gut contents of juvenile Chinook salmon. Missing data indicate episodes in which sampling was not conducted or no Chinook salmon of a size appropriate for gastric lavage were encountered.

3.1.6.3 Prey Electivity

Apportioning ambiguous diet items had little effect on electivity values and, in turn, no impact on conclusions that may be drawn from model output (Figure 3.9 and Figure 3.10). Thus, no contrasts between 100% and 50% scenarios (see Section 2.5.3.2) are described below. Because %IRI values identified three taxa generally to be most important across sampling episodes (Diptera, Amphiopoda and Cladocera; Figure 3.8), electivity values for only these prey items are presented. These taxa were never consumed in proportion to their abundance in the environment (i.e., E_i*= 0.0) across the three prey pools considered in analyses.

Benthic Prey

Electivity values for Diptera varied both spatially and temporally. At Site B, when dipterans were encountered in gut content and/or benthic samples, the taxon was selected against. While dipterans were selected against at Site E during November of 2010, during February and July of 2011, the prey item was associated with positive electivity index values. Dipterans were moderately selected for at Site C during July, the only applicable sampling month. Like dipterans, electivity index values calculated for benthic amphipods varied considerably. At Site B, amphipods were selected for both during November and July.

During November at Site E, the crustaceans were strongly selected against; however, at the same site in July, amphipods appeared to be a preferred prey item. As was found during November at Site E, amphipods were strongly selected against at site C during July (Figure 3.9 and Figure 3.10).

Drifting Prey

Electivity index values for drifting dipterans varied relatively little; of six sampling episodes, in only one (February 2011 at site E) did juvenile salmon select for dipterans. Generally, the taxon was moderately to strongly selected against. Index values calculated for amphipods displayed greater variability. These macro-crustaceans were preferred prey during November and July at site B, but selected against during July at sites E and C. Across all applicable sampling episodes, cladocerans were strongly selected against (Figure 3.11 and Figure 3.12).

Terrestrial and Winged Prey

Electivity values for winged and terrestrial dipterans also varied considerably across sampling episodes. Dipterans were selected against at Site B during November and at Sites C and E during July. Alternatively, the prey appeared to be preferred at Sites B and E during July and November, respectively (Figure 3.13).

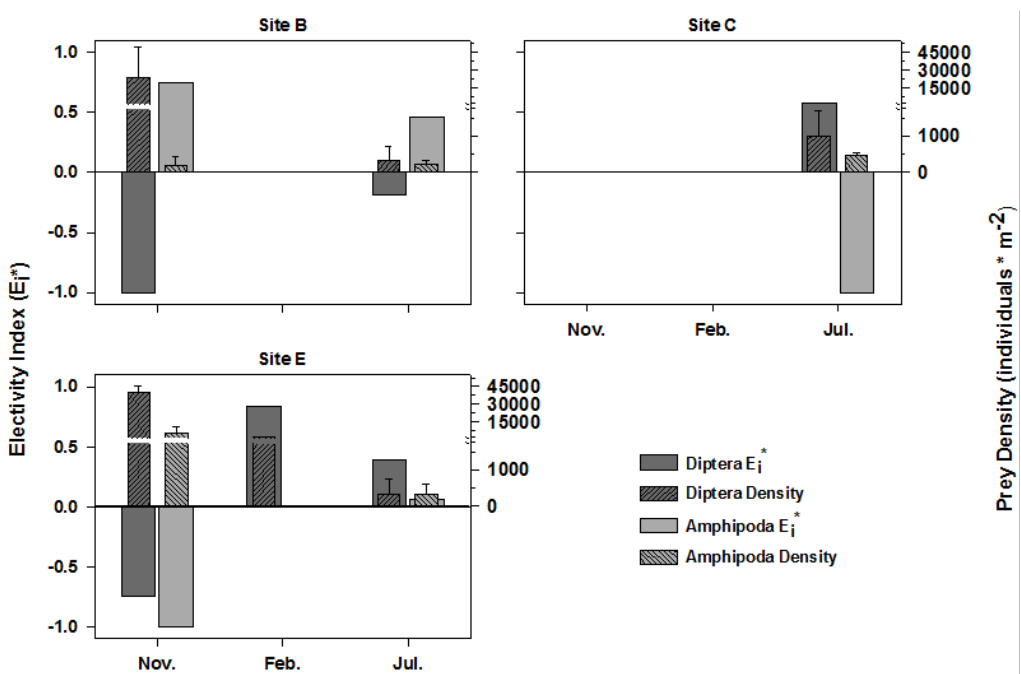

Figure 3.9. Relativized electivity index values and prey densities calculated for major benthic prey items. Values were calculated with 100% of the "ambiguous" prey items allocated to benthic production. Across sampling episodes, these taxa were never consumed in proportion to their abundances in the environment (E* = 0.0). No Chinook salmon of a size appropriate for gastric lavage were encountered at Site N during months indicated in the figures.

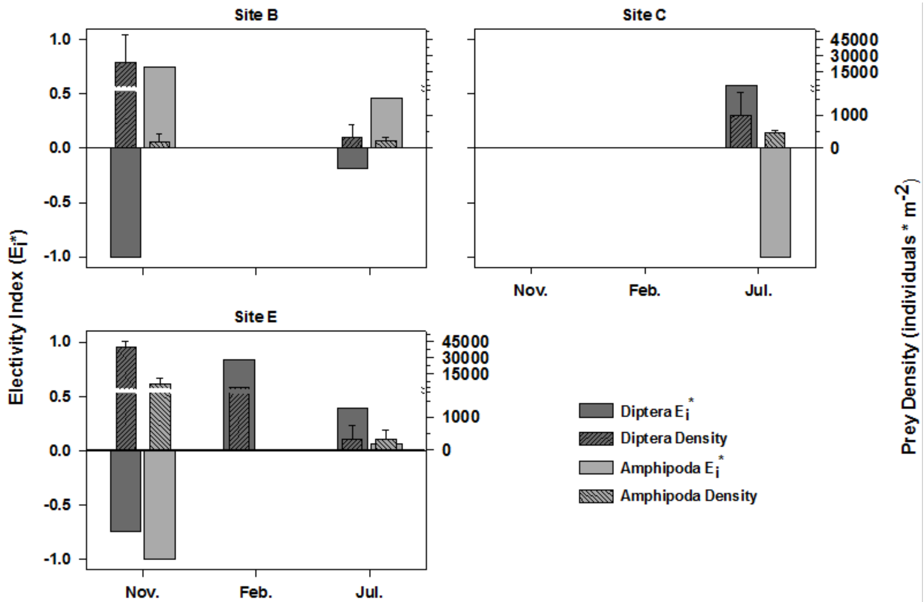

Figure 3.10. Relativized electivity index values calculated for major benthic prey items. Values were calculated with 50% of the "ambiguous" prey items allocated to benthic production. Across sampling episodes, these taxa were never consumed in proportion to their abundances in the environment (E* = 0.0). No Chinook salmon of a size appropriate for gastric lavage were encountered at Site N during months indicated in the figures.

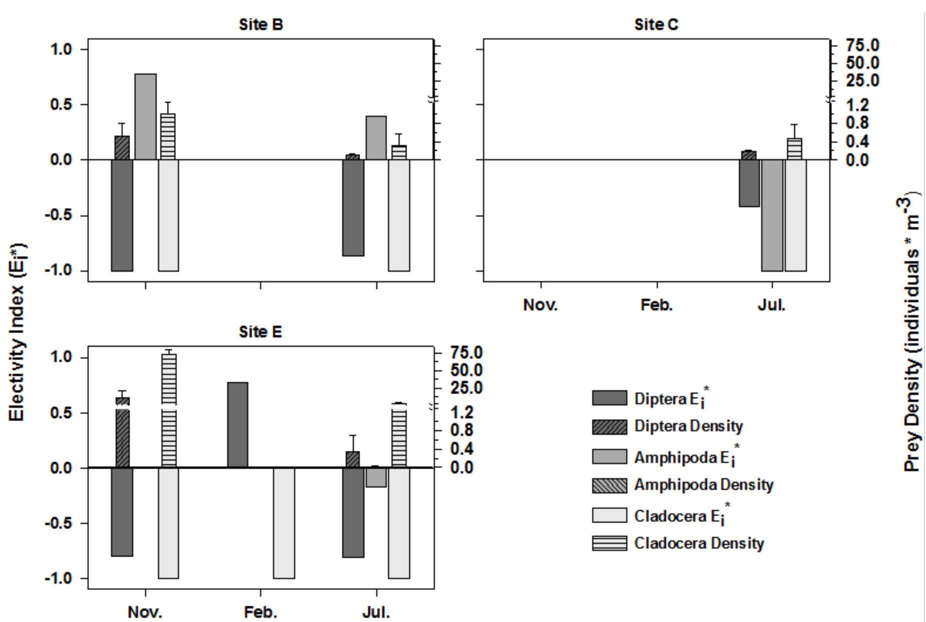

Figure 3.11. Relativized electivity index values and prey densities calculated for major drifting prey items. Values were calculated with 100% of the "ambiguous" prey items allocated to benthic production. Across sampling episodes, these taxa were never consumed in proportion to their abundances in the environment (E* = 0.0). No Chinook salmon of a size appropriate for gastric lavage were encountered at Site N during months indicated in the figures. Error bars represent one standard deviation.

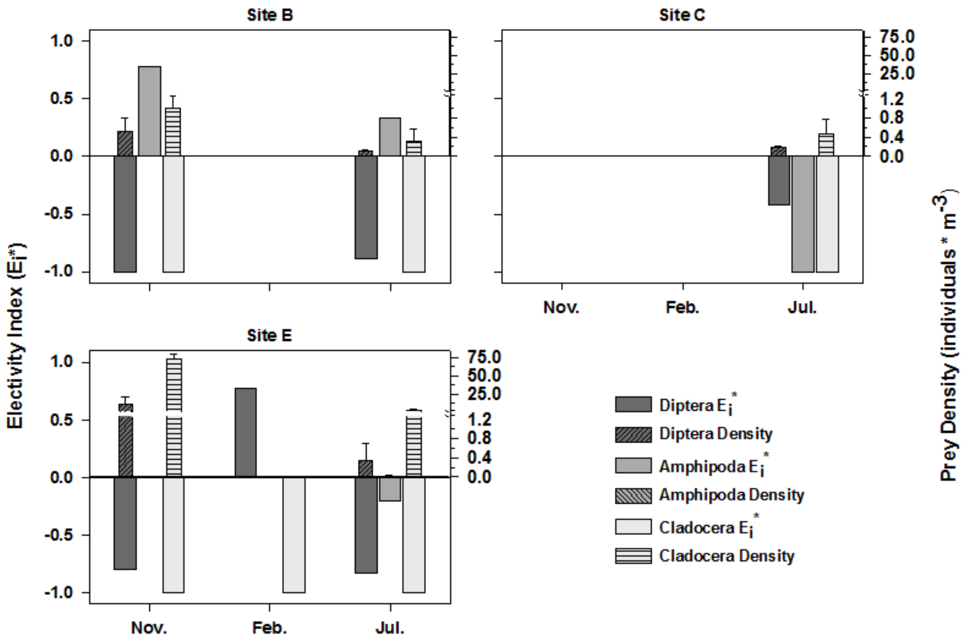

Figure 3.12. Relativized electivity index values and prey densities calculated for major drifting prey items. Values were calculated with 50% of the "ambiguous" prey items allocated to benthic production. Across sampling episodes, these taxa were never consumed in proportion to their abundances in the environment (E* = 0.0). No Chinook salmon of a size appropriate for gastric lavage were encountered at Site N during months indicated in the figures. Error bars represent one standard deviation.

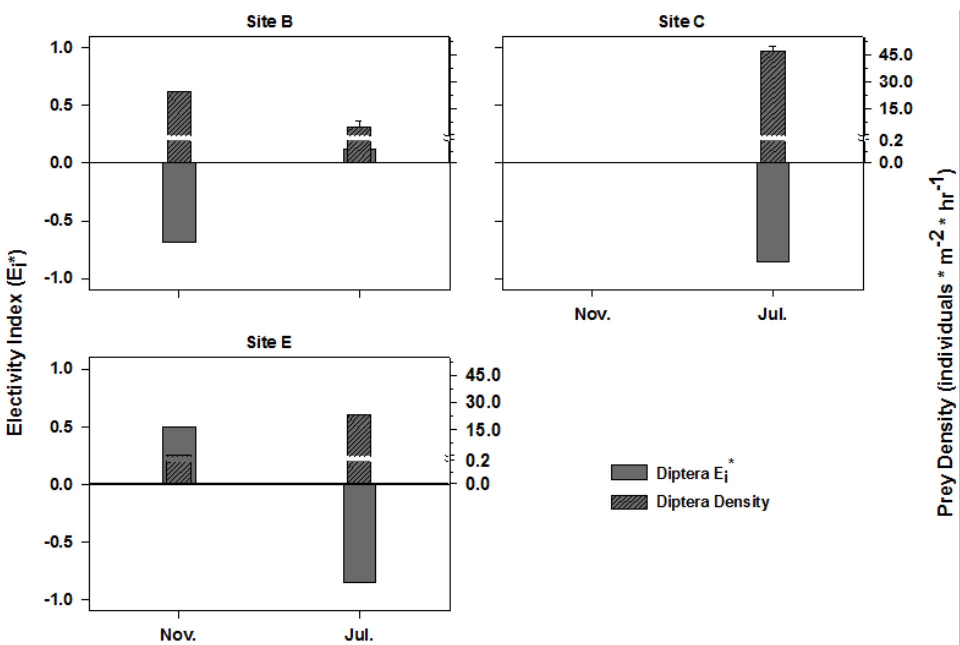

Figure 3.13. Relativized electivity index values and prey densities calculated for major terrestrial or winged prey items. Across sampling episodes, these taxa were never consumed in proportion to their abundances in the environment (E* = 0.0). No Chinook salmon of a size appropriate for gastric lavage were encountered at Site N during months indicated in the figures. Error bars represent one standard deviation.

3.1.7 Fish Diet Overlap

Across most sampling episodes, index values for diet overlap did not exceed suggested benchmark indicating biological significance (i.e., C_{xy}>0.60; Zaret and Rand 1971; Mathur 1977). Two exceptions occurred during July 2011 at Site B, where the diets of both killifish and stickleback overlapped significantly with that of Chinook salmon (0.71 and 0.61, respectively). In addition to those comparisons that were found to be biologically significant at Site B, during June 2010, the diets of stickleback and Chinook salmon approached significant overlap (C_{xy} = 0.57). Otherwise, index values at this site generally were small, indicating little or no overlap. Diet separation between salmon and resident species at Site C was, on average, less than at Site B (Site C, mean C_{xy} = 0.31 ± 0.20 s.d; Site B, mean C_{xy} = 0.23 ± 0.30 s.d.), driven primarily by moderate index values between Chinook salmon and bluegill, killifish, and stickleback during May 2010, June 2010, and July 2011, respectively. While the overlap between Chinook salmon and both killifish and stickleback at Site E periodically was near moderate levels, index values were more commonly low (<0.12 during 10 of 13 applicable sampling episodes). At Site N during May 2010, there appeared to be a greater separation in diet between bluegill and Chinook salmon versus killifish and the salmon species, yet in both cases index values were relatively low (C_{xy} = 0.05 and 0.24, respectively). Of the four resident fish species included in analyses of diet overlap, on average, killifish and stickleback displayed the greatest potential overlap with Chinook salmon (mean $C_{Chinook,killifish}$ = 0.21 ± 0.22 s.d; mean $C_{Chinook,stickleback}$ = 0.24 ± 0.23 s.d), but index values varied considerably (Figure 3.14).

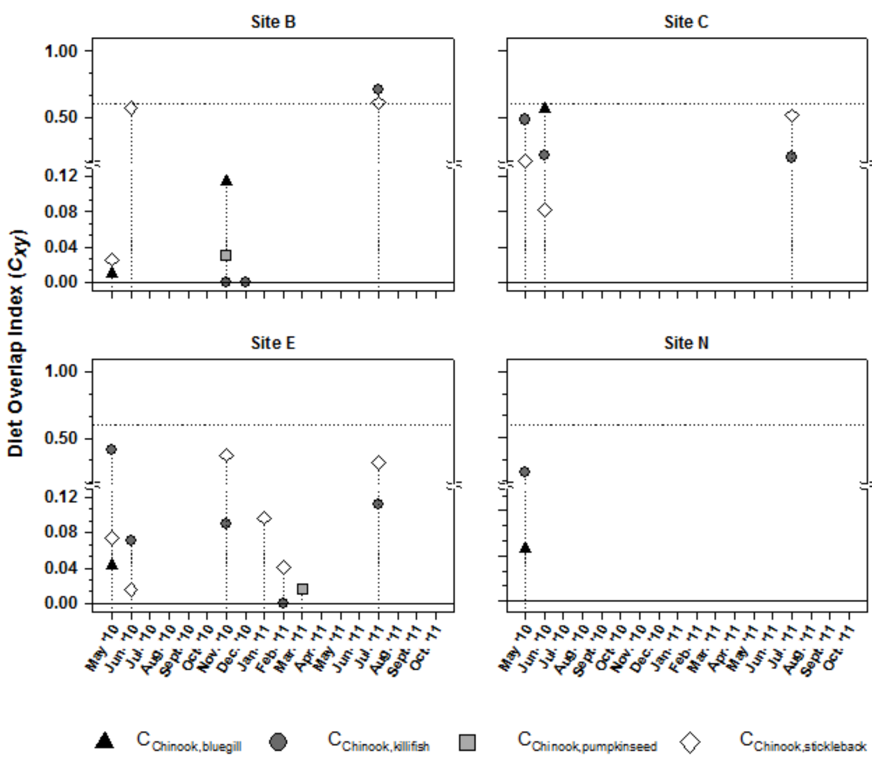

Figure 3.14. Diet overlap index values for Chinook salmon and four non-salmonid species. The dashed line identifies the benchmark (0.60) above which index values are generally considered biologically significant (Zaret and Rand 1971; Mathur 1977).

3.1.8 Water Chemistry

Physical and biogeochemical water property attributes are summarized in Figure 3.15 and Figure 3.16, averaged by date and by site, respectively. The attributes include temperature, DO, TSS, POC, nitrate, phosphate, and chlorophyll-*a*. The water temperature was similar between sites for each date (Figure 3.15a and Figure 3.16a), with Site N slightly lower than the others. Seasonal variations in water temperature that corresponded to water chemistry sampling ranged from a mean low of 5.7°C (February 2011) to a mean high of 17.9°C (July 2011; Figure 3.15a). The temperature was similar between years—November 2010 (10.2°C) and November 2011 (10.8°C). Likewise, the mean DO levels were similar in the fall between years—November 2010 (11.6 mg/L) and November 2011 (12.0 mg/L) (Figure 3.15b). DO levels at most sites increased in February to ~14 mg/L, and decreased to ~11 mg/L during July with the exception of Site N, which had distinctly lower levels than other sites and greater variability, particularly during February (6.3 mg/L) and July (3.2 mg/L) (Figure 3.15b and Figure 3.16b). Salinity was <0.2 psu during all sample collections.

TSS concentrations ranged from a mean low of 1.6 mg/L in November 2011 to a mean high of 5.6 mg/L in February 2011 (Figure 3.15c). With the exception of Site N with the highest concentration overall (13 mg/L, November 2010) and the highest variability of any site (Figure 3.16c), the percent inorganic fraction of TSS was determined for November 2010 and February 2011 and ranged between 53% and 87%. POC ranged from a mean low of 0.53 mg/L in February to a mean high of 1.0 mg/L in July (Figure 3.15d). Site N had the highest POC levels of all sites each month (Figure 3.16d) with the exception of February. POC, expressed as a percentage of TSS, ranged between 10% and 55%.

Nitrate concentrations ranged between a mean high of 280 µg/L in February to a mean low of 36 µg/L in July (Figure 3.15e). Site N had higher levels compared to all other sites in November 2010 but notably lower levels by one to two orders of magnitude during other months (Figure 3.16e). For example, a low of 6.7 µg/L (Site N, February 2011) was reflected in the high variance on that date (Figure 3.15e). The mean phosphate concentrations show a similar trend when compared to nitrate, both by date and by site (compare Figure 3.15f to e, and Figure 3.16f to e), with a mean high in February, and a mean low in July. Site N was lower than other sites during February, July, and November 2011, resulting in a lower mean of 3.2 µg/L (Figure 3.16f).

Mean chlorophyll-a levels were similar throughout the study, ranging from a low in February of 1.9 mg/L to a high in July of 3.8 µg/L (Figure 3.15g). The mean for Site N was slightly higher than other sites (Figure 3.16g), but the levels were not as dissimilar as other parameters (e.g., POC, nutrients).

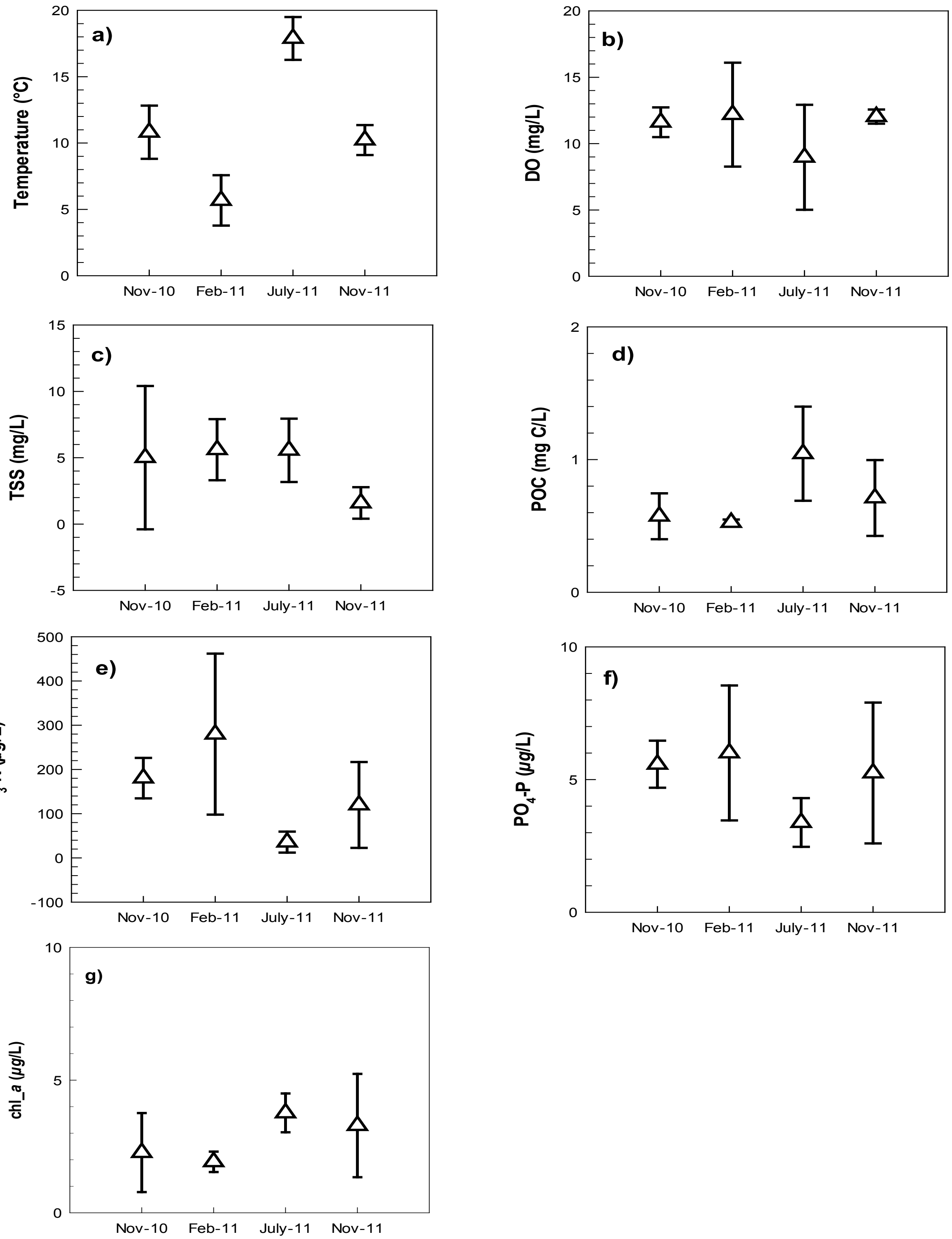

Figure 3.15. Mean results (±1 SD) from all sites (B, C, E, And N) of water property sample collections during November 2010, February, July, and November 2011 for A) temperature, B) dissolved oxygen, C) total suspended sediment, D) particulate organic carbon, E) nitrate, F) phosphate, and G) chlorophyll *a*.

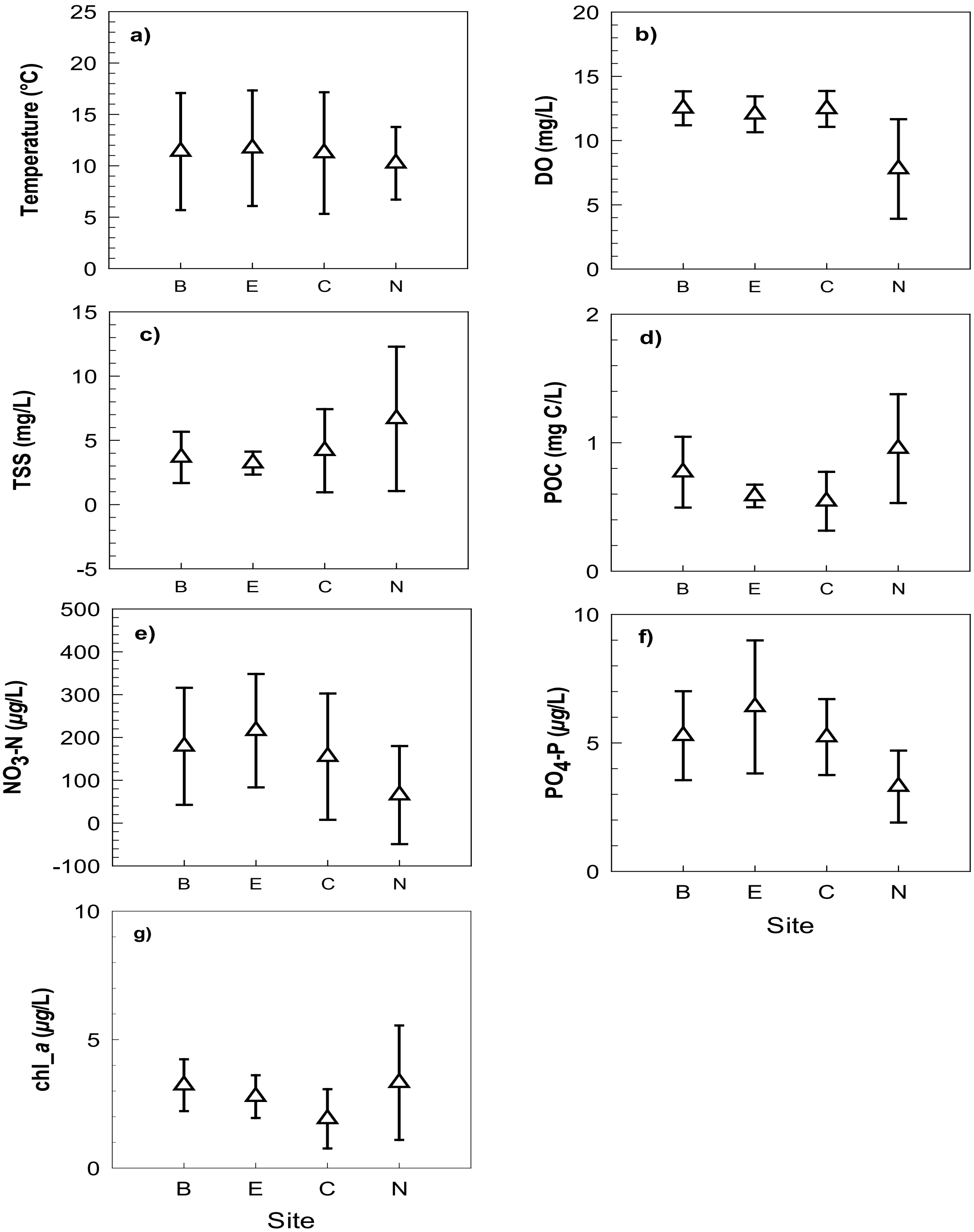

Figure 3.16. mean results (±1 SD) from all dates (November 2010, February, July, and November 2011) of water property sample collections at Sites B, C, E, and N for A) temperature, B) dissolved oxygen, C) total suspended sediment, D) particulate organic carbon, E) nitrate, F) phosphate, and G) chlorophyll *a*.

A nMDS plot summarizes the similarities and differences of the water property attributes plotted in Figure 3.17. The stress statistic of 0.09 indicates a reasonable representation of the data as a 2D ordination plot. In general, the data indicate similarity by date for November 2010, February 2011, July 2011, and to a lesser extent for November 2011. The exception is Site N, which was dissimilar from all other sites and dissimilar among sampling periods. The data summarized in Figure 3.15 and Figure 3.16 also indicate differences at Site N, particularly for DO, TSS, POC, and nutrients.

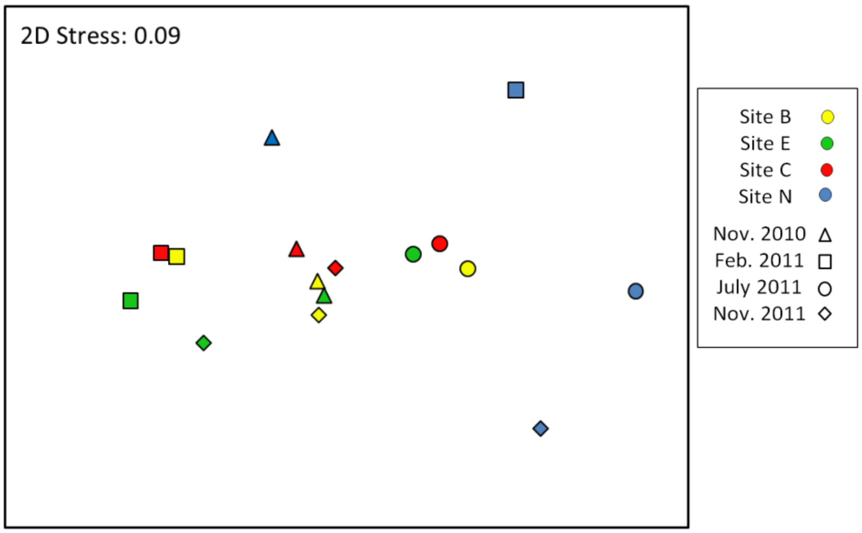

Figure 3.17. Non-metric multidimensional scaling (nMDS) ordination plot of all sites and dates sampled, based on water property attributes of temperature, DO, chl-*a*, TSS, POC, and nutrients. Proximity indicates similarity in attributes.

3.2 Comparison of Landscape-Scale Fish Characteristics

Fish density comprises characteristics of the fish community and the salmon at the landscape scale.

3.2.1 Fish Communities

While there were some differences in abundance and species composition between SRD and LRR during the winter and summer sampling events, the proportions of salmon (~1%), native (~78%), and non-native taxa (~21%) were similar between the study areas. A nMDS plot of the SRD and LRR sites indicated the clustering of samples based on fish communities most closely corresponded to the season in which they were sampled. Clustering was greatest during summer months for LRR sites. Although the SRD sites clustered to some extent by season, the between-site similarities in fish community composition did not occur to the same degree as observed with the LRR sites. The stress value (0.09) indicates the 2D nMDS plot adequately fits the similarity matrix (Figure 3.18).

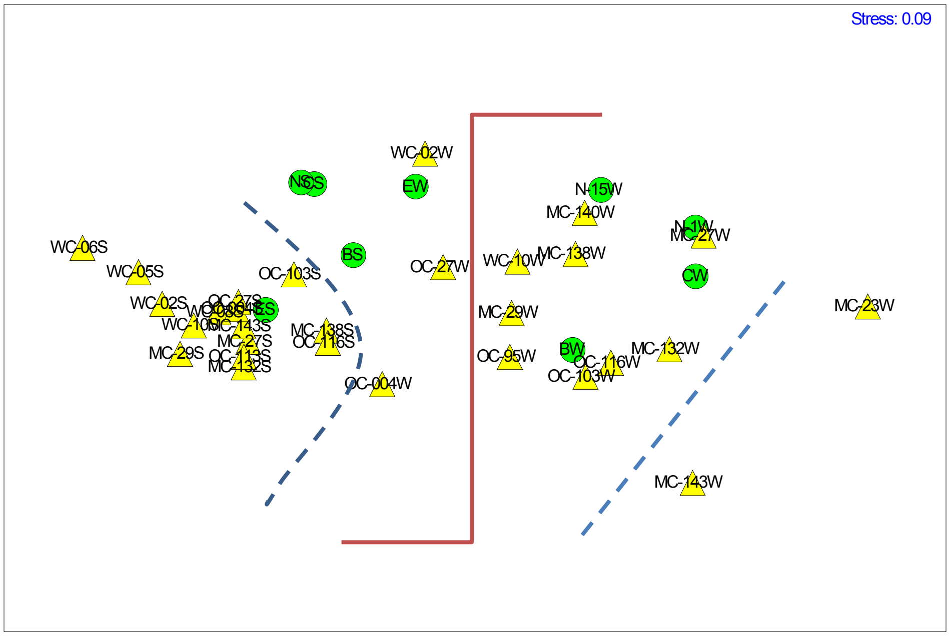

Figure 3.18. Non-metric multidimensional scaling (nMDS) plot of fish assemblages sampled at LRR and SRD during February and July 2011. Green = SRD, yellow = LRR; season is indicated by S or W in sample name, where S = summer, W = winter. Solid red line separates two primary clusters identified by Bray-Curtis similarity at a similarity value of 17.6%; dashed blue lines separate secondary clusters within each main group at similarity values of 36.1% (left cluster) and 29.5% (right cluster).

3.2.2 Salmon Catch

Although the proportion of salmon captured in each of the study areas was approximately 1% of the total catch during the winter and summer, the total fish abundance was greater at the LRR compared to the SRD, as was the proportion of unmarked Chinook salmon (Table 3.5). Unmarked Chinook salmon yielded the greatest relative abundance across multiple sites and habitat strata in the LRR during the summer compared to the winter. However, an examination of relative abundance by stations revealed the greatest abundance of unmarked Chinook salmon occurred at an off-channel site (near the mouth of the Cowlitz River) during the winter (Figure 3.19).

Table 3.5. Percentage of salmonids captured during February and July at the SRD and LRR sites.

Latin Name	Common Name	SRD	LRR
Oncorhynchus tshawytscha	Chinook	74.5	90.0
Oncorhynchus tshawytscha	Hatchery Chinook	23.6	6.6
Oncorhynchus kisutch	Coho	0	1.4
Oncorhynchus kisutch	hatchery Coho	0	0
Oncorhynchus keta	Chum	1.8	1.9
Oncorhynchus mykiss	Steelhead (Hatchery)	0	0
Oncorhynchus clarki clarki	Cutthroat	0	0.1

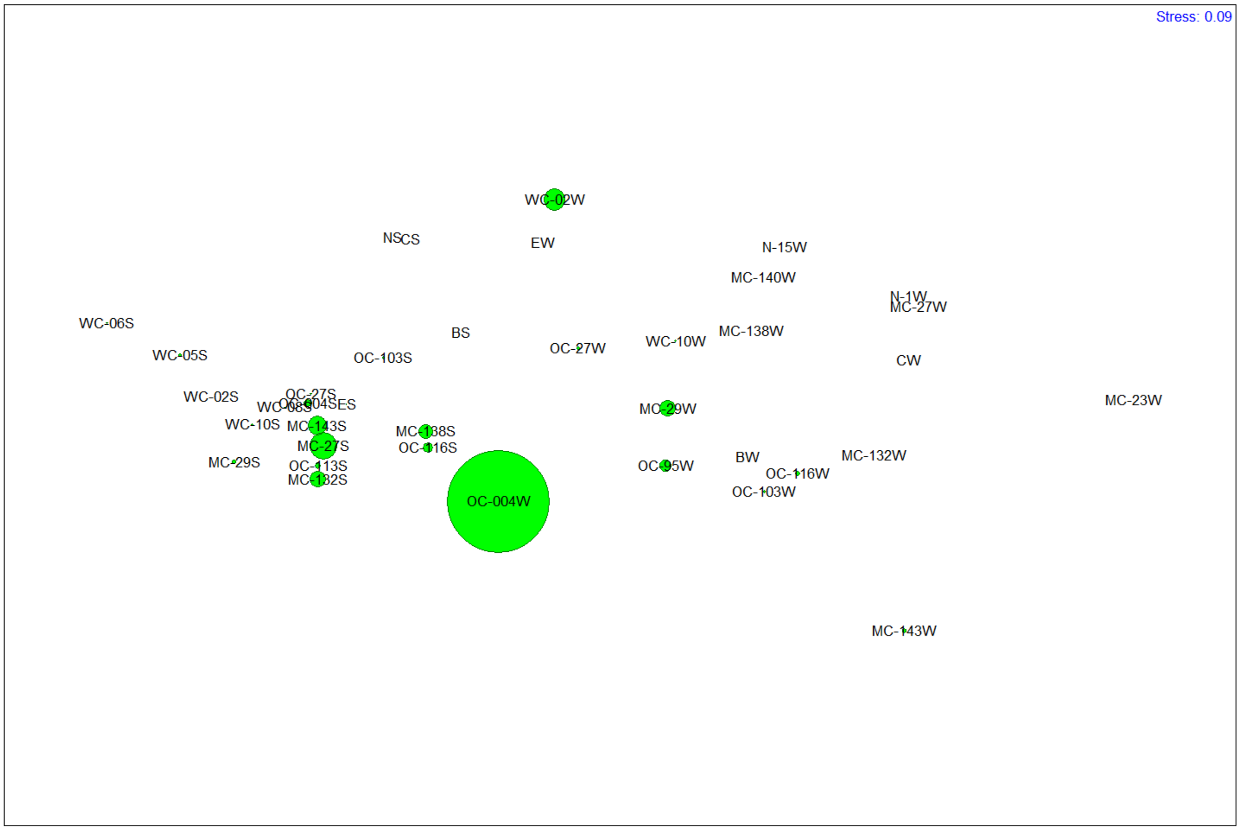

Figure 3.19. Non-Metric Multidimensional Scaling Plot of Relative abundance of unmarked Chinook salmon sampled at LRR and SRD sites. Larger circles indicate a greater abundance of fish sampled at a given site during a specified time period (S = summer, W = winter).

Size differences in unmarked Chinook salmon were observed across the study areas and to some extent across the habitat strata in the LRR. During February and July, the median FL for unmarked Chinook salmon captured at the SRD was larger compared with unmarked Chinook salmon captured at the LRR (Kruskal-Wallis test, $P < 0.001$). Size differences of marked hatchery Chinook salmon between the study areas could not be evaluated in February due to inadequate sample size at the SRD. However, size differences in marked hatchery Chinook salmon sampled during July were not significant (Mann-Whitney test, $P = 0.714$; Figure 3.20).

The size of unmarked Chinook salmon at the LRR during winter did not differ across the three habitat strata: main channel, off channel, and wetland channel (Kruskal-Wallis test, $P = 0.195$). There were significant differences in the sizes of unmarked Chinook salmon during summer at LRR (Kruskal-Wallis test, $P < 0.001$). Compared with unmarked Chinook salmon captured in off-channel and wetland-channel sites, those sampled from the main channel were smaller in size. The largest unmarked Chinook salmon captured in the LRR were encountered in the wetland sites (Figure 3.21).

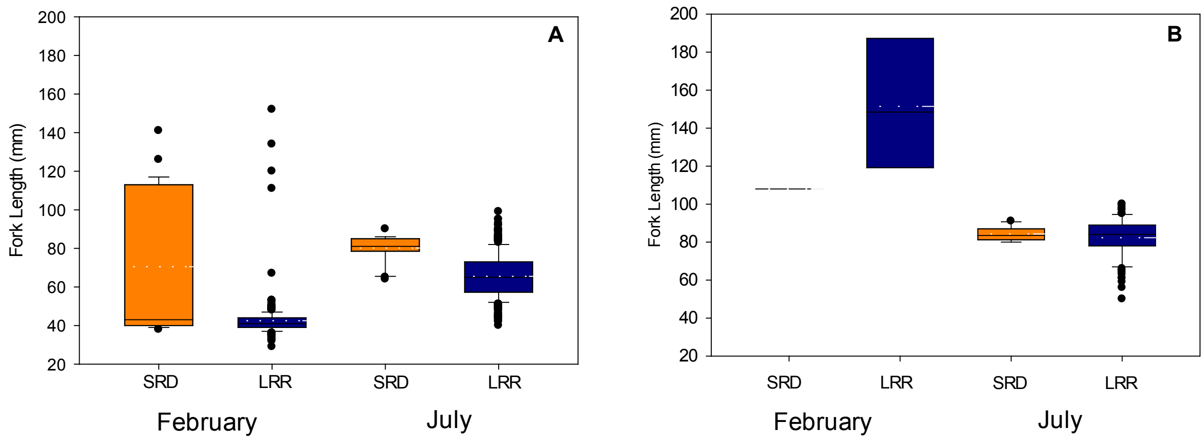

Figure 3.20. Size of unmarked Chinook salmon (A) and marked Chinook salmon (B) captured at he SRD and LRR sites during winter and summer 2011. Box and whiskers are the 90th and 10th percentiles. Solid line within the box indicates the median length while the dashed line denotes the sample mean. Solid black dots indicate the sample outliers.

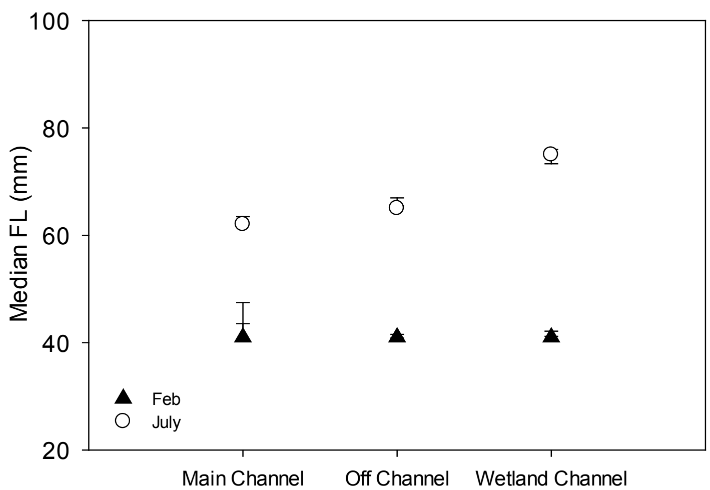

Figure 3.21. Median fork length (mm) for unmarked Chinook salmon sampled during winter and summer 2011. Error bars represent standard deviation.

3.2.3 Landscape-Scale Genetic Stock Identification

Estimated stock proportions of unmarked Chinook salmon sampled in the LRR (N = 285) are reported in Table 3.6. Most fish were estimated to be from the West Cascade Tributary Fall stock group (76%). Much smaller proportions were estimated for the Spring Creek Group Tule Fall (9%), West Cascade Tributary Spring (6%), Upper Columbia Summer/Fall (6%), and Willamette River Spring (3%) stocks. No other stock groups were present in these samples. The largest proportion of fish in the sample of marked Chinook salmon from the LRR (N = 53) was from West Cascade Tributary Fall (59%), Spring Creek Group Tule Fall (17%), and Upper Columbia Summer/Fall (10%), with smaller contributions from West Cascade Tributary Spring (7%), Deschutes River Fall (4%), and Willamette River Spring (2%) stock groups (Table 3.7).

Table 3.6. Estimated percentage genetic stock group composition and 95% confidence intervals of 285 unmarked juvenile Chinook salmon sampled at LRR sites in February and July 2011.

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	6.2	3.2	9.4
West Cascade Tributary Fall	75.9	66.4	79.4
Spring Creek Group Tule Fall	8.9	3.6	13.5
Snake River Fall	0.0	0.0	2.5
Willamette River Spring	2.9	0.7	4.2
Deschutes River Fall	0.0	0.0	2.8
West Cascade Tributary Spring	6.2	5.5	14.8
Mid and Upper Columbia River Spring	0.0	0.0	0.0
Snake River Spring	0.0	0.0	0.1
Rogue River	0.0	0.0	0.0

Table 3.7. Estimated percentage genetic stock group composition and 95% confidence intervals of 53 marked juvenile Chinook salmon sampled at LRR sites in February and July 2011.

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	9.7	0.0	22.5
West Cascade Tributary Fall	58.7	42.7	77.9
Spring Creek Group Tule Fall	16.5	3.3	28.5
Snake River Fall	1.7	0.0	11.6
Willamette River Spring	1.9	0.0	5.6
Deschutes River Fall	3.9	0.0	11.5
West Cascade Tributary Spring	6.7	0.0	14.9
Mid and Upper Columbia River Spring	0.9	0.0	5.6
Snake River Spring	0.0	0.0	0.5
Rogue River	0.0	0.0	0.2

Individual fish genetic stock assignments of samples of unmarked SRD and LRR fish were grouped by survey and are presented in Figure 3.22. Genetics sample sizes of the surveys ranged from 1 to 149 individuals. Stock proportions of unmarked Chinook salmon sampled at the SRD showed a strong seasonal pattern with Spring Creek Group Tule Fall fish predominating in samples collected from January to April and decreasing or absent in later surveys. The Upper Columbia Summer/Fall stock was the largest contributor to SRD samples in May, June, and July and present in catches in surveys conducted throughout much of the year. Exceptions were in November and December 2010 when only five fish were analyzed. During February and July 2011 when both the SRD and LRR sites were sampled, the genetic stock compositions of the two study areas were markedly different. LRR samples in both February and July were dominated by the West Cascade Tributary Fall stock. The second largest contributors to LRR samples were the Spring Creek Group Tule Fall in February and Upper Columbia Summer/Fall fish in July.

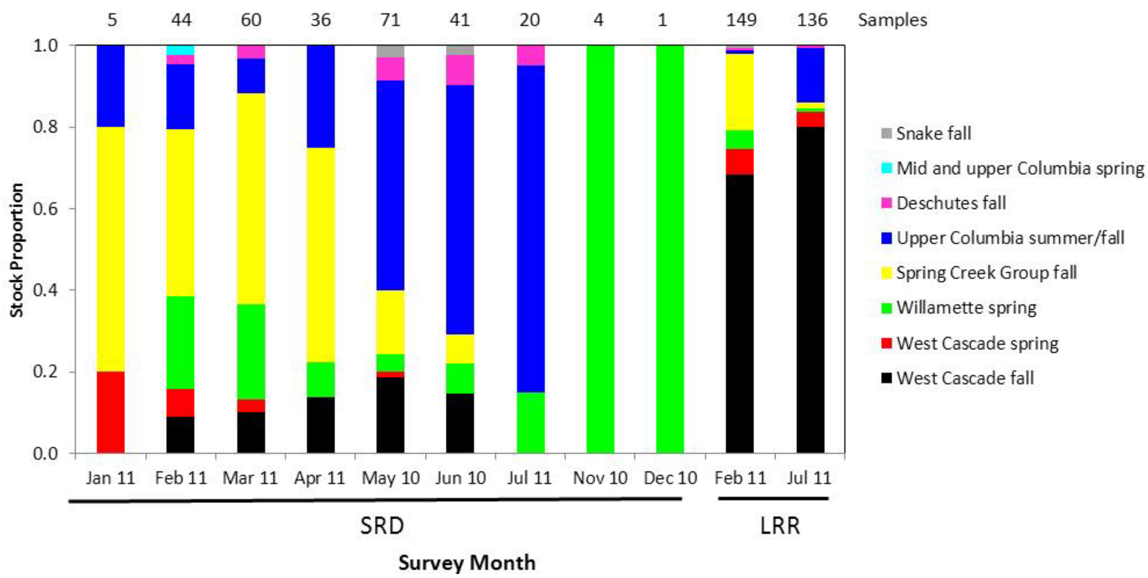

Figure 3.22. Estimated stock proportions and sample sizes of unmarked juvenile Chinook salmon sampled at SRD and LRR **s**ites May 2010 through July 2011. The month and year of sampling is indicated. Snake River spring and Rogue River fall stock groups were estimated to contribute <1% in all of the surveys and are not shown.

3.3 Residence Time Study

The analysis of residence time included the identification of genetic stocks, time juvenile salmon spent in residence, their exit timing and distribution, and fish length and weight relative to residence time.

3.3.1 Tagged Fish Genetic Stock Identification

Of the 48 tagged fish, 12 were Chinook and 36 were coho salmon. Based on genetic stock identification (Teel et al. 2009), the Chinook salmon stocks were mostly of the Willamette spring stock (9), likely spring Chinook salmon from the Sandy River bearing the Willamette genetic "signature" from past hatchery stocking. One fish was assigned to the West Cascade spring stock, two were from the upper Columbia River summer/fall stock, and two were from the West Cascade fall Chinook salmon stock. Separate residence time analyses were conducted for Chinook and coho salmon. The mean FLs and weights of the tagged fish were similar between the two species (Table 3.8).

Table 3.8. Mean fork lengths and weights for juvenile Chinook and coho salmon tagged during February 2–16, 2011, for the residence time study in the vicinity of the Sandy River delta.

	Chinook Salmon	Coho Salmon
Mean Fork Length (mm)	115	116
Mean Weight (g)	16	16

3.3.2 Residence Time

Median residence times were approximately 11 days for both Chinook and coho salmon (Table 3.9). The mean residence times for Chinook and coho salmon were 25 and 29 days, respectively. One coho salmon stayed in the study area for almost 3 months and one coho salmon had not left before the nodes were retrieved on May 17, 2011.

Table 3.9. Residence time (d) statistics for tagged Chinook and coho salmon behind Gary Island from February 3 through May 17, 2011.

Statistic	Chinook Salmon	Coho Salmon
Minimum	0.09	0.02
Maximum	73.68	89.78
Mean	24.68	28.56
Median	11.61	11.22
n	12	36

3.3.3 Exit Timing and Distribution

Acoustic tagged Chinook and coho salmon both exited the study over the 3-month monitoring period—February through mid-May 2011 (Figure 3.23). More fish exited during February (7 and 19, respectively) than during the other months when exit timing was reasonably uniform. Seven coho salmon exited during May after residing in the study area for over 3 months.

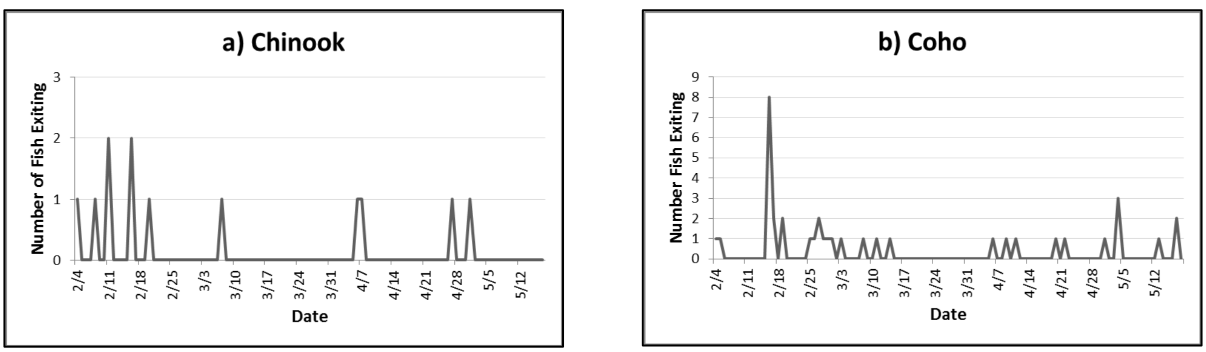

Figure 3.23. Exit timing (fish per day) for A) Chinook salmon and B) coho salmon.

The exit distribution of acoustically tagged Chinook and coho salmon, as indicated by the node of last detection, was skewed to the downstream end of the study area (Figure 3.24). Eighty-three percent of the last detections for both Chinook and coho salmon were at the two downstream-most nodes (#6076 and #7089).

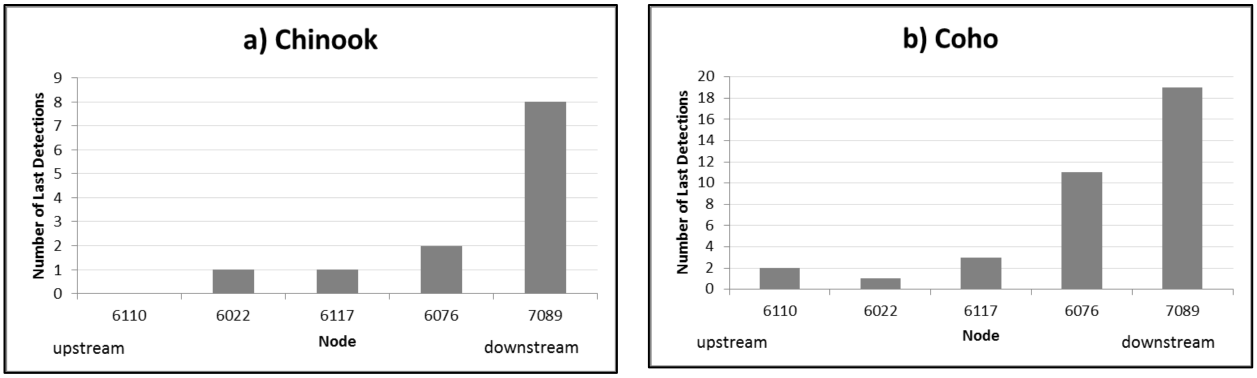

Figure 3.24. Node where tagged fish were last detected for A) Chinook salmon and B) coho salmon.

3.3.4 Fish Length and Weight Versus Residence Time

There was a non-significant negative relationship between fish length and residence time for Chinook salmon (*P*=0.284, Figure 3.25a) and for coho salmon (P = 0.115, Figure 3.25b). The Chinook salmon weight and residence time relationship also was not significant (P = 0.239, Figure 3.25c). Conversely, there was a significant negative correlation between coho salmon weight and residence time (P = 0.036, Figure 3.25d).

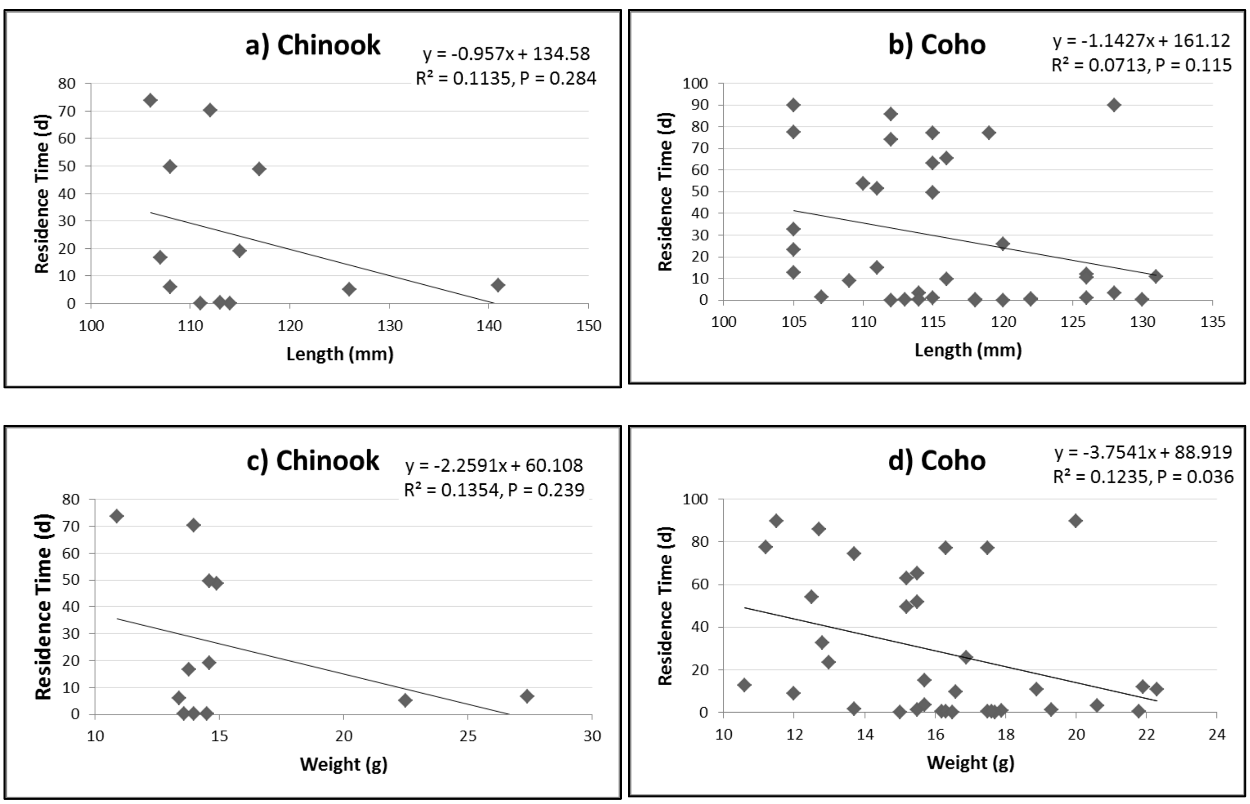

Figure 3.25. Relationship Between residence time and fish length and weight at the time of tagging for Chinook salmon (3a and 3c, respectively) and coho salmon (3b and 3d, respectively).

4.0 Discussion

The ensuing discussion includes juvenile salmon characteristics and ecology, limitations and potential solutions, implications to CEERP management, and recommendations for future research.

4.1 Juvenile Salmon Characteristics and Ecology

The trends in fish community composition noted at the SRD are similar to those observed during previous years of sampling (Sather et al. 2011). During the 2010–2011 sampling effort, beach seine catches were dominated by native taxa, but non-native species composed approximately 21% of the total catch. Summer and fall yielded the highest densities for native (excluding salmon) and non-native taxa, respectively. Eight species accounted for 99% of our total catch (Table 3.1), six of which were reported as commonly captured taxa during previous sampling efforts at the SRD (Sather et al. 2011).

Juvenile salmon were most abundant at the SRD during spring months. As found in our previous work, unmarked Chinook salmon were the most commonly encountered salmonid. Patterns associated with length frequency distribution were also similar to those previously reported by Sather et al. (2011). Two distinct groups of unmarked Chinook salmon were captured at the SRD during winter months. The size and timing of these groups are indicative of subyearling and yearling life history groups. During the transition to spring months, the composition of unmarked Chinook salmon was predominantly small subyearling fish.

Genetic stock groups are characterized by patterns associated with life history attributes as well as geographic patterns (Waples et al. 2004; Narum et al. 2010). However, transfers of hatchery stocks in the Columbia River basin have confounded our ability to definitively link some genetic stock groups with natal sources. Examples include the Spring Creek Group Fall, Upper Columbia Summer/Fall, and the Willamette River Spring stock groups (see Sather et al. 2009 and 2011 for additional discussion).

Despite the confounding factors limiting our ability to discern geographic origins of some fish in our samples, the genetic stock composition estimates presented in this report are similar to results obtained earlier (Sather et al. 2011), indicating that trends in genetic stock distribution of Chinook salmon are spatially and temporally consistent. The percentages of the major contributors to our unmarked SRD samples collected from May 2010 to July 2011, the Upper Columbia River Summer/Fall (35%) and Spring Creek Group Tule Fall (31%) stocks, were very similar to those Sather et al. (2011) reported for June 2007 through April 2010 (33% and 35%). The five stocks contributing minor percentages (2%–15%) were also the same during both sampling periods, as were the three stocks estimated to be absent or nearly absent. In addition, the seasonal shifts in SRD habitat use reported by Sather et al. (2011) were also apparent in our current results, with Spring Creek Group Tule Fall run fish most abundant from February to April and Upper Columbia River Summer/Fall stock most abundant from May to July. While very few Chinook salmon juveniles were analyzed from November and December sampling (N = 5), these were Willamette River spring Chinook stock, which were the predominate fish in previous years' fall collections. These fish are most likely from the nearby Sandy River, which has a spring run stock with a genetic profile consistent with the sustained introductions of Willamette River stock.

Genetic estimates for LRR unmarked samples collected in 2011 were also similar to those obtained in 2009 and 2010 (Sather et al. 2011). West Cascade Tributary Fall stock contributed an estimated 76% to both the recent samples and to those collected during the earlier period. While our unmarked samples may include both naturally produced and unmarked hatchery fish (Sather et al. 2009), we also analyzed a smaller number of marked fish sampled at sites in the SRD (N = 50) and LRR (N = 53). SRD samples of known hatchery fish were largely (84%) from the two lower river fall stocks, a result similar to that reported by Sather et al. (2011) for previous years. LRR marked fish were composed of a higher percentage of West Cascade Tributary Fall stock in 2011 than in 2009 and 2010 (59% vs. 24%), likely reflecting a seasonal difference in stock distribution. Nearly all of the current samples were taken in July, whereas most of marked LRR samples in previous years were collected in February and May.

The consistency of the new data with those from previous years suggests that major stock distribution patterns in Columbia River tidal freshwater habitats may remain relatively stable across years. These consistencies include both temporal (seasonal) and spatial (SRD vs. LRR) patterns for several different stocks. While the Chinook salmon juveniles in these habitats are primarily from three fall run stock groups (Upper Columbia River Summer/Fall, Spring Creek Group Tule Fall, and West Cascade Tributary Fall), our samples also consistently include much smaller numbers of spring run fish from both lower river and interior basin sources.

Several taxa periodically were important in the diets of juvenile Chinook salmon at our sites. However, dipterans most frequently constituted substantial proportions of the gut content biomass and were commonly associated with large %IRI values. This pattern is consistent with previous findings in the tidal freshwater portion of the lower Columbia River (Storch and Sather 2011) and the Columbia River Estuary proper (Lott 2004; Bottom et al. 2008). Members of the order Diptera account for most of the macroinvertebrates in freshwater environments (Bode 1990). Given potentially high encounter rates, the importance of these invertebrates in our diet samples might be expected. During May of 2010, cladoceran biomass overwhelmingly dominated the diets of juvenile Chinook salmon at our sites. Pervasiveness of cladocerans (i.e., non-malacostracan crustaceans) was not encountered during any other months in the current study nor in previous years (see Storch and Sather 2011). The abundance of cladoceran taxa in the diets of Chinook salmon during May of 2010 and the relative absence of these microcrustaceans during other periods underscores the variability of prey pool composition as well as the flexible foraging behaviors (i.e., niche plasticity) exhibited by juvenile salmon at our sites. Other large-bodied prey (e.g., amphipods, hemipterans, odonates, non-dipteran aquatic insects and fish) periodically were important in the diets of juvenile Chinook salmon at our sites. Although the role of these commonly energy-rich taxa (Cummins and Wuycheck 1971) appeared inconsistent, periodic consumption by juvenile Chinook salmon could help maximize energy acquisition.

While dipterans consistently accounted for large proportions of prey in gut contents of juvenile salmon, with relatively few exceptions, juvenile salmon selected against these prey items. A similar pattern was identified by Storch and Sather (2011) over a broader area in the tidal freshwater portion of the Lower Columbia River. As indicated by proportions of biomass and IRI scores of gut contents, dipterans play an important role in the diet of Chinook salmon, and yet these prey taxa appear to be largely avoided (per electivity index results). These results suggest, at least in terms of the dipteran resource, the ostensible productivity of shallow tidal freshwater habitats near the SRD and their potential to support juvenile Chinook salmon.

In addition to avoidance of dipterans, juvenile Chinook salmon were also found to avoid cladocerans, despite the fact that these taxa were at times highly abundant in the water column. Prey size is an important factor contributing to encounter rates for particulate feeders (Gerking 1994). Given small sizes of cladoceran taxa, it seems logical that the microcrustaceans were largely under-represented in the diet, and when abundant, the zooplankters were selected against. Cladocerans are commonly poor in energy and certain essential molecules (Cummins and Wuycheck 1971; Storch 2005). Thus, avoidance of the invertebrates by juvenile Chinook salmon, or selection for higher-quality prey, could help promote vital life functions (e.g., growth, visual acuity, membrane fluidity, etc.). Lack of preference for small prey such as cladocerans may be adaptive (Storch and Sather 2011)—and is perhaps indicative of an optimal foraging strategy (Pyke et al. 1977).

While variability in prey selectivity was encountered for benthic and drifting amphipods, during several sampling episodes, these large crustaceans were preferred. Size-biased feeding—where consumers actively select larger prey—has been well documented in the literature (see Gerking 1994). Considered in the context of optimal foraging theory (Pyke et al. 1977; Gerking 1994), preference for large-bodied, typically energy-rich, prey such as amphipods could be nutritionally beneficial to juvenile salmon foraging in the tidal freshwater portion of the lower Columbia River.

Dietary overlap was generally weak across our sites during months in which the gut contents of both Chinook salmon and resident species were collected. Based on the putative benchmark (0.60) proposed by others (e.g., Zaret and Rand 1971; Mathur 1977), there were only two instances in which overlap was significant. These findings may suggest, during certain times at our sites, there exists low potential for interspecific competition between Chinook salmon and the four resident species. However, our assessment of diet overlap, and any inferences about resource competition that may be drawn, was constrained, in part, by the periodicity with which we sampled. The diet data we collected represent a "snapshot" of the most recently consumed prey items. While little overlap was observed during most periods in which we sampled, diet shifts occurring between sampling episodes may result in stronger overlap, potentially leading to a cumulative competitive impact (e.g., reduced growth) on Chinook salmon. To elucidate shifts in diet (i.e., variability in diet overlap) and better inform inferences about competitive interactions among sympatric species, more frequent sampling or the use of time-integrated information (e.g., stable carbon isotopes) to corroborate gut content data is necessary.

This reporting period marks the first summary of water properties data collected at the SRD by this project. This task provided a preliminary characterization of site-specific water property attributes during four time periods throughout the year. Although only four time periods were sampled, the general pattern of nutrient concentrations through time was similar to that found at Cottonwood Island (Woodruff et al. 2011) and other studies in the lower river and estuary (Sullivan et al. 2001; Lara-Lara et al. 1990; Frey et al. 1984; Haertel et al. 1969) where a reduction in nutrients is evident as phytoplankton production increases during summer months and light levels increase. The range of TSS was similar but slightly less than tidal freshwater sites sampled 83 km downstream near Cottonwood Island between May 2010 and 2011 (range of 3–10 mg/L) (Woodruff et al. 2011). The percent inorganic fraction of TSS for the SRD sites was similar to results found near Cottonwood Island. Levels of chl-*a* measured at SRD fell within the range of lower levels found for other studies (Woodruff et al. 2011; Sullivan et al. 2001). Levels of particulate organic carbon were slightly higher than was found near Cottonwood Island and other studies closer to the estuary proper (Prahl et al. 1998; Sullivan et al. 2001).

We noted several spatial and temporal trends in the water property data at the SRD. Seasonal differences were observed throughout the year at all sites and were greater than site-specific differences, with the exception of Site N. For each sampling period, the water property attributes of Sites B, C, and E, were similar; but Site N was notably different (e.g., TSS, DO, POC, and nutrients) and exhibited higher variability than other sites. The lower surface water flow, hyporheic flow, and lack of connectivity to the main stem Columbia River at Site N may offer a partial explanation of the differences observed.

In previous research, we documented extensive residence by juvenile Chinook salmon in the SRD during winter and early spring months (Johnson et al. 2011b). In 2010, several genetic stock groups of juvenile Chinook salmon were found to have a mean winter-spring residency of 34 days. Our findings from 2011 support our previous work in that juvenile Chinook and coho salmon resided in the off-channel area behind Gary Island near the SRD from February through April (mean 25 and 29 days, respectively). A portion of the tagged fish migrated out of the study area soon after release in February, as evidenced by the median residence times of 11 days for both Chinook and coho salmon. The median residence time for Chinook salmon in 2011 (11 days) was lower than the median residence time for Chinook salmon during 2010 (26 days; Johnson et al. 2011b).

Our landscape-scale comparison indicated that the community composition of fish is similar across broad expanses of tidal freshwater segments of the LCRE; however, we experienced higher densities of fish at the LRR sites compared to the SRD. The statistical plan (see appendix) for examining landscape-scale densities of juvenile salmon was not fully implemented until July 2011; therefore, the analysis associated with this sampling design is not included as part of this reporting cycle. Regardless, our results indicate that fish assemblages are most closely explained by seasonal trends as opposed to trends linked to sites, habitat strata, or study region. We found a greater proportion of unmarked Chinook salmon in the LRR and a higher proportion of marked hatchery Chinook salmon in the SRD. We also noted that unmarked Chinook salmon sampled in the SRD were significantly larger than those sampled from LRR sites. This trend was not apparent for the marked hatchery Chinook salmon sampled from the two study regions.

4.2 Limitations and Potential Solutions

Study limitations and potential solutions for this research included the following:

- High water velocities and water-surface elevations prevented beach seine sampling events during 2011. In the future, we will consider augmenting our sampling by electrofishing when necessary. This method will not allow us to make direct comparisons with density data obtained from beach seine efforts, but it will allow us to collect data relevant to several of our other research objectives - juvenile salmon diet, and genetic stock compositions.
- Past and current transfers of hatchery stocks in the Columbia Basin confound our ability to link some genetic stock groups (e.g. Spring Creek Group Fall, Upper Columbia River Summer/Fall, Willamette spring) to natal geographic region.
- Although hatchery marking rates (proportion of hatchery fish that are marked) have increased over the years, incomplete marking continues to prevent unambiguous identification of hatchery fish in our samples.

- To elucidate shifts in diet (i.e., variability in diet overlap) and better inform inferences about competitive interactions among sympatric species, more frequent sampling or the use of time-integrated information (e.g., stable carbon isotopes) to corroborate gut content data is necessary.
- The water chemistry sampling designed lacked a reference point for the off-channel and wetland sites sampled at the SRD. Obtaining data from a nearby upstream main channel location would provide additional context with which to evaluate metrics observed at the SRD.
- Research to date has been limited to fish (>95 mm), which do not necessarily represent migratory behavior for the gamut of size groups for juvenile salmon. Smaller acoustic transmitters to tag juvenile salmon are needed.

4.3 Implications to the CEERP Management

This research, although designed to evaluate the effectiveness of restoration actions, has implications for resolving uncertainties in the CEERP knowledge base. The 2012 CEERP Synthesis Memorandum is under development by the Action Agencies. The results of our 2011 research will inform the 2012 CEERP Synthesis Memorandum. The memorandum is an annual work product from the CEERP process that is intended to provide a comprehensive compilation of science to date concerning juvenile salmon ecology and ecosystem restoration in the LCRE. In addition our research to date has involved site-scale, pre-restoration sampling for the proposed rechannelization at the SRD and landscape-scale sampling in the LRR. While the restoration action is pending, the findings have these implications for particular uncertainties, as identified (italicized below) by the Action Agencies (2012).

- "*ecological interactions between juvenile salmon and other aquatic native and non-native aquatic and plant species; significance of these interactions and hybrid food webs are not clear (ISRP 2011)*"

  Our previous bioenergetics work on juvenile Chinook salmon at the SRD suggested that competition for prey resources may be weak (Storch 2011). Our current investigation of the diets of Chinook salmon and resident species (bluegill, pumpkinseed, killifish, and stickleback) indicates dietary overlap, during certain periods, was generally weak across our four sites. Our investigation was limited to the SRD, and should not be extended to other regions of the LCRE without additional investigation.

- *"juvenile salmon residence times, growth rates, and bioenergetics in tidal freshwater, estuarine, and main channel habitats"*

  Our research on residence time indicates juvenile salmon (Chinook and Coho) used tidally influence freshwater portions of the Lower Columbia River for extended times periods from mid-winter through early spring months. Our previous research on bioenergetics modeling (Storch 2011) at the SRD suggests feeding rates and gross conversion efficiency were sufficient for the allocation of energy to somatic growth for juvenile salmon.

- *"temporal and spatial abundance, stock composition, habitat use, and residency of unmarked and marked juvenile salmon"*

  We note distinct temporal trends in the abundance of juvenile salmon. While we capture several species of salmonids (e.g., chum, coho, steelhead) unmarked Chinook salmon were the most prevalent in our catches at both SRD and LRR study areas. Spring yielded the highest densities of juvenile salmon, the majority of which were quite small in size (e.g. fry to parr). Abundance of salmon generally decreased during summer and fall months but began to increase during winter. During winter months the bimodal size distribution of unmarked Chinook salmon denoted the co-occurrence of multiple life stages (e.g., fry and yearling) at the SRD.

- *"trends over time in landscape estimates of juvenile salmon density as related to multiple collective restoration actions"*

  Although an empirical analysis of landscape-scale salmon densities is premature (because only one sampling event was available), we anticipate addressing this CEERP concern in future reporting.

- *"wintertime use of off-channel reference and restored areas, and extent and frequency of movements of juvenile salmonids from the main stem up into tributary areas; approximately what fraction of salmon populations use the habitats and for how long?"*

  Based on acoustic telemetry of tagged fish (>95 mm), juvenile salmon are residing in shallow, tidal freshwater habitats during winter (see Section 3.3.2 and Johnson et al. 2011). Future investigations to tag smaller juvenile salmon will provide further information on this topic. Investigations of up-tributary movements from the main stem are planned for 2012.

4.4 Recommendations

In closing, we offer the following recommendations for future elements of this ongoing study.

- Revisit the likelihood of the implementation of SRD rechannelization. If the prospects of restoration are low (<10% chance), prioritize and select new location(s) for site-scale Action Effectiveness Research in fiscal year 2013.
- Coordinate with other researchers performing action effectiveness studies to reassess and prioritize the most useful and practical monitored indicators for ecosystem structure and function.
- Continue to identify genetic stocks of Chinook salmon sampled in shallow, tidal freshwater habitats to build a comprehensive genetics database in collaboration with other researchers in the LCRE.
- Coordinate with other research to assess the feasibility of implementing field-based measures aimed at examining physiological attributes indicative of health and fitness of juvenile salmon in habitats of the LCRE.
- Design mark-recapture studies for juvenile salmon use of off-channel shallow water sites, pre- and post-restoration.
- Given the extensive data set for this study (from 2007 into 2012), examine the statistical associations between juvenile Chinook salmon density (unmarked fish) and various environmental attributes, such as water temperature, habitat type, and vegetation percent cover.
- Based on our initial findings of little dietary overlap between juvenile Chinook salmon and resident species, and given the level of effort necessary to further strengthen inferences made regarding competitive interactions between fish species (e.g. intensive sampling frequency) we recommend discontinuing the investigation of dietary overlap. This will permit us to focus our efforts on tasks that may provide more meaningful results with respect to project goals and objectives.

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Appendix

2011 Statistical Plan for the Multi-Scale Study of Salmon Density

Appendix

2011 Statistical Plan for the Multi-Scale Action Effectiveness Research of Salmon Density

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1.0 Introduction

The purpose of the Multi-scale (MS) action effectiveness research project is to relate changes in salmonid density with restoration efforts over time. Beach seine sampling will be used to estimate salmonid density across habitats and river reaches to determine if estuarine restoration efforts are benefiting salmon populations. A rotational sampling scheme will be employed to detect changes in salmon density over time and to assure the monitoring project reflects the current river environment. Specific objectives are as follows:

1. Estimate mean salmonid density in major river environments.
2. Estimate mean Chinook salmon smolt density in major river environments.
3. Estimate annual changes in salmon density estuary-wide and by habitat type.
4. Relate changes over time in salmonid density with restoration effects within the tidal freshwater environment.

Concurrent with these objectives, information on non-salmonid and non-native fish densities will also be collected and related to ongoing restoration efforts in the estuary.

2.0 Sampling Design

The sampling frame consists of all riverine site within geomorphic reaches D, E, F, and G of the Lower Columbia River (LCR) that are accessible by beach seining (Figure 2.1). The sites within these reaches have been stratified into three habitat types:

1. Main channel (includes main channel and main channel islands)
2. Off channel (includes off channel and off-channel islands)
3. Wetlands

As such, the sampling frame consists of three strata (= three habitat types) (Table 2.1), which will be monitored using a rotational sampling plan.

The within-year sampling will consist of four seasonal sampling events centered on the months of February, May, July, and November. These four months were selected because they represent periods of either high salmonid presence or shifts in salmonid species composition over the annual cycle.

Figure 2.1. Locations of all possible beach seine sites within geomorphic reaches D, E, F, and G in the Lower Columbia River. These sites constitute the sampling frame for the multi-scale research project of salmonid densities.

Table 2.1. Number of available beach seining locations by river reach and habitat type in the sampling frame for the multi-scale action effectiveness research project.

River reach	Habitat	Available sampling locations (N_{kl})
D	Main channel	38
	Off channel	21
	Wetland	6
E	Main channel	54
	Off channel	42
	Wetland	6
F	Main channel	96
	Off channel	85
	Wetland	0
G	Main channel	78
	Off channel	88
	Wetland	1

During each of the seasonal sampling periods, a minimum of five sites will be canvassed at each of the three habitat strata. The monitoring program will begin with a random sample of sites from each stratum (Table 2.1). These selected sites will be retained for a complete annual cycle. Each year, 2/5 of the sites will be systematically rotated out of the sampling schedule and replaced with new sites randomly selected from the sampling frame on the anniversary date (Table 2.2). The monitoring program will therefore be on a 2-year rotational schedule. In other words, a site will be in the survey sample for an average of 2 years before being replaced by a new site (less time in the initial three years of the project until the rotational schedule is fully implemented). This rotational or panel design (Rao et al. 1964, Sen 1979, Skalski 1990, McDonald 2003) has precision benefits when monitoring for both status (i.e., current conditions) and trends (i.e., changes over time).

On each visit to a monitoring site, two beach seines will be collected to better estimate mean salmonid density at a location. Consecutive beach seines at a site will be separate by 30 minutes to allow nominal fish densities to reestablish themselves between seining events. The area swept will be measured in each seining event in order to calculate fish density.

Table 2.2. Schematic of a 2/5 site rotation per year in a simple rotational sampling design.

	Site										
Year	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
1											
2											
3											
4											
⋮											

3.0 Statistical Analysis

It is anticipated that estimates of mean fish density during the four intra-annual months sampled will not themselves be compared. The fish populations represented by these four months of the year (i.e., February, May, July, and November) are inherently different in stock composition and behavior (i.e., migrant vs. residualized). Instead, trends over time will be compared primarily between specific months across years. In so doing, the fish stocks represented by the different months of the sampling will be evaluated over time and with regard to their responses to restoration activities that might be stock specific.

3.1 Estimates of mean density in the current year

Mean fish density will be estimated for the entire river and separately by habitat stratum. Define:

d_k^{ij} = fish density (i.e., fish/m^2) in the *j*th seine $(j = 1, 2)$ at the *i*th site $(i = 1, \ldots, 4)$ in the *k*th habitat $(k = 1, \ldots, 3)$;

N_k = total number of sites in the *k*th habitat $(k = 1, \ldots, 3)$;

n_k = number of sites actually canvassed in the *k*th habitat stratum $(k = 1, \ldots, 3)$;

r = number of beach seines collected per location.

For convenience, subscripts for month or year of sampling will be ignored in this section.

3.1.1 Density within stratum

The average fish density in the kth stratum will be estimated as

$$\hat{\bar{D}}_k = \bar{d}_k = \frac{\sum_{i=1}^{n_k}\left[\frac{\sum_{j=1}^{r} d_k^{ij}}{r_j}\right]}{n_k} = \frac{\sum_{i=1}^{n_k}\hat{D}_k^i}{n_k}, \tag{1}$$

with associated variance

$$\mathrm{Var}\left(\bar{D}_k\right) = \left(1-\frac{n_k}{N_k}\right)\frac{S_1^2}{n_k} + \frac{S_2^2}{n_k r}, \tag{2}$$

where

$$S_1^2 = \frac{\sum_{i=1}^{N_k}\left(\bar{D}_k^i - \bar{\bar{D}}_k\right)^2}{\left(N_k - 1\right)} \tag{2A}$$

and

$$S_2^2 = \frac{\sum_{i=1}^{N_k}\sum_{j=1}^{M}\left(D_k^{ij} - \bar{D}_k^i\right)^2}{N_k\left(M-1\right)}, \tag{2B}$$

and where

$$\bar{D}_k^i = \frac{\sum_{i=1}^{M} d_k^{ij}}{M},$$

$$\bar{\bar{D}}_k = \frac{\sum_{i=1}^{N_k}\sum_{j=1}^{M} d_k^{ij}}{N_k M},$$

for M (i.e., potential beach seines that could be collected at a site) very large. The variance expression (2) can be estimated by the sample data where

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_k\right) = \frac{\left(1-\frac{n_k}{N_k}\right)s_1^2}{n_k} + \frac{\frac{n_k}{N_k}s_2^2}{n_k r}, \tag{3}$$

where

$$s_1^2 = \frac{\sum_{i=1}^{n_k}\left(\bar{d}_k^i - \bar{d}_k\right)^2}{\left(n_k - 1\right)}$$ = between-site-within-stratum variance, (3A)

and

$$s_2^2 = \frac{\sum_{i=1}^{n_k}\sum_{j=1}^{r}\left(d_k^{ij} - \bar{d}_k^i\right)^2}{\sum_{j=1}^{n_k}\left(r_j - 1\right)}$$ = between-beach-seines-within-a-site variance, (3B)

and where

$$\bar{d}_k^i = \frac{\sum_{j=1}^{r} d_k^{ij}}{r_j} = \hat{\bar{D}}_k^i$$ = mean density at site i.

Estimator (1) and variance estimator (3) are used to estimate mean fish density and its variance within each of the three habitat strata.

3.1.2 Estuary-wide density

Average fish density across the three habitat strata (i.e., "estuary-wide") will be estimated by the weighted average

$$\hat{\bar{\bar{D}}} = \frac{\sum_{k=1}^{3} N_k \hat{\bar{D}}_k}{\sum_{k=1}^{3} N_k}, \tag{4}$$

with variance

$$\mathrm{Var}\left(\hat{\bar{\bar{D}}}\right) = \sum_{k=1}^{3} W_k^2 \cdot \mathrm{Var}\left(\hat{\bar{D}}_k\right), \tag{5}$$

where

$$W_{kl} = \frac{N_k}{\sum_{k=1}^{3} N_k},$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\bar{\bar{D}}}\right) = \sum_{k=1}^{3} W_k^2 \widehat{\mathrm{Var}}\left(\hat{\bar{D}}_k\right). \tag{6}$$

The weights W_k are appropriate for making inferences back to the sampling frame of sites accessible to beach seining. If, in addition, the weights are representative of the proportions of habitat, then inferences may be extended to the shorelines in the survey reach.

3.2 Retrospective adjustment of $\hat{\bar{D}}_k$ in year t using year $t+1$ data

The monitoring design has an annual rotational fraction of f = 2/5. Sites within a stratum are replaced each year with new locations selected at random from the sampling frame. Because of the positive correlation in fish density between consecutive years (e.g., February 2011 to February 2012), the estimate of density in the past year can be updated with an anticipated improvement in precision. The degree of precision improvement will depend on the degree of interannual correlation.

In any initial year t, the estimate of mean density is composed of an estimate of $\hat{\bar{D}}_k$ based on matched sites (sites sampled in both years t and $t+1$) and non-matched sites (sampled in year t but not year $t+1$). An updated estimate of $\hat{\bar{D}}_k$ in year t, taking into account the positive correlation in density over time, can be computed as

$$\tilde{\bar{D}}_k = W \cdot \hat{\bar{D}}'_U + (1-W) \cdot \hat{\bar{D}}'_M , \tag{7}$$

where

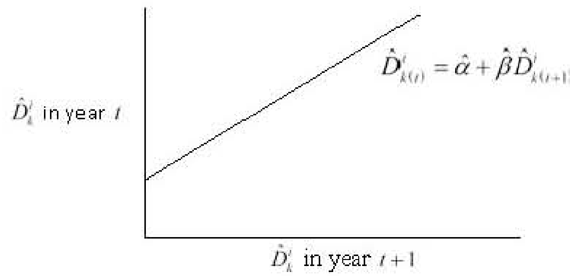
$$\hat{\bar{D}}'_{U1} = \frac{\sum_{i=1}^{u} \sum_{j=1}^{r} d_k^{ij}}{ur} , \tag{8}$$

= estimated mean based on unmatched (u) sites surveyed in strata k (nominally $u \geq 2$),

$\hat{\bar{D}}'_{M1}$ = revised estimate of mean density in year t based on regression of matched density values in years t and $t+1$, where

$$\hat{\bar{D}}'_{M1} = \alpha + \beta \left(\hat{\bar{D}}_{M2} \right), \tag{9}$$

$\hat{\bar{D}}'_{M2}$ = estimated mean density in year $t+1$ for the matched sites, and where the regression relationship is



using the m matched sites collected in both years t and $t+1$ (nominally $m \geq 3$).

The weights in Equation (7) are of the form

$$W = \frac{\dfrac{1}{\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{U1}\right)}}{\dfrac{1}{\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{U1}\right)} + \dfrac{1}{\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)}} = \frac{\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)}{\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{U1}\right) + \widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)}. \tag{10}$$

In turn,

$$\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}_{U1}\right) = \frac{\left(1 - \dfrac{u}{N_{k1}}\right) s_1^2}{u} + \frac{\dfrac{u}{N_{k1}} s_2^2}{ur}, \tag{11}$$

based on Equation (3).

The variance of $\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)$ is based on double sampling (Cochran 1977:339), in which case,

$$\widetilde{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right) = \frac{\mathrm{MSE}}{m} + \frac{s^2_{D_{k1}} - \mathrm{MSE}}{n} - \frac{s^2_{D_{k1}}}{N_k}, \tag{12}$$

where

m = number of matched sites (i.e., $n - u = m$),

$$s^2_{D_M} = \frac{\sum_{i=1}^{m}\left(\hat{D}^i_k - \hat{\bar{D}}_{M1}\right)^2}{(m-1)}, \tag{12A}$$

$$\hat{\bar{D}}_{M1} = \frac{\sum_{i=1}^{m}\hat{D}^i_k}{m} \text{ for site-specific estimates in year } t,$$

MSE = the MSE from the ANOVA for the regression of $\hat{D}^i_k$ in year t versus $\hat{D}^i_k$ in year $t+1$.

Cochran (1977:346-347) shows the variance estimator (7) has the expected value of

$$\mathrm{Var}\left(\bar{\bar{D}}_k\right) = \frac{\left(1-\frac{n}{N}\right)S_1^2\left(n-u\rho^2\right)}{\left(n^2-u^2\rho^2\right)}.$$

Optimal fraction $\left(P_{\mathrm{OPT}}\right)$ of n that should be matched one year to the next is

$$P_{\mathrm{OPT}} = \frac{\sqrt{1-\rho^2}}{1+\sqrt{1-\rho^2}}, \tag{13}$$

where ρ is the coefficient correlation from year t to year $t+1$.

In practice, if fish densities are not different between habitats, it may be possible to pool observations across habitats within the river reach when performing the regression analysis and the retrospective estimation of abundance.

3.3 Estimating differences in fish density between years t and $t+1$

Let the $\hat{D}^i_k$ be the average density estimate at site i in stratum k based on matched samples (i.e., sites sampled in both years t and $t+1$) in year t. Let $\hat{D}^{i'}_k$ be the average density estimate at site i in stratum k based on matched samples in year $t+1$. Then the difference in fish density between years t and $t+1$ at site i in stratum k is

$$\hat{\Delta}^i_k = \hat{D}^{i\prime}_k - \hat{D}^i_k. \tag{14}$$

The estimate of the average change in fish density in stratum k between years t and $t+1$ is the

$$\hat{\bar{\Delta}}_k = \frac{\sum_{i=1}^{n_k}\hat{\Delta}^i_k}{n_k}. \tag{15}$$

An estimate of "estuary-wide" change in fish density between years t and $t+1$ can then be calculated as a weighted average, where

$$\hat{\hat{\Delta}} = \frac{\sum_{k=1}^{3} N_k \hat{\hat{\Delta}}_k}{\sum_{k=1}^{3} N_k} \tag{16}$$

with variance

$$\mathrm{Var}\left(\hat{\hat{\Delta}}\right) = \sum_{k=1}^{3} W_k^2 \ \mathrm{Var}\left(\hat{\hat{\Delta}}_k\right), \tag{17}$$

where

$$W_k = \frac{N_k}{\sum_{k=1}^{3} N_k},$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\hat{\Delta}}\right) = \sum_{k=1}^{3} W_k^2 \ \widehat{\mathrm{Var}}\left(\hat{\hat{\Delta}}_k\right). \tag{18}$$

In turn, the variance of $\hat{\hat{\Delta}}_k$ can be expressed as

$$\mathrm{Var}\left(\hat{\hat{\Delta}}_k\right) = \left(1 - \frac{m_k}{N_k}\right)\frac{S_{\Delta_k}^2}{m_k} + \frac{\left(S_2^2 + S_2^{2'}\right)}{m_k r}, \tag{19}$$

where

$$S_{\Delta_k}^2 = \frac{\sum_{i=1}^{N_k}\left(\Delta_k^i - \Delta_k\right)^2}{\left(N_k - 1\right)}, \tag{19A}$$

S_2^2 = Equation (2B) for year t,

$S_2^{2\prime}$ = Equation (2B) for year $t+1$.

This variance can be estimated by

$$\widehat{\mathrm{Var}}\left(\hat{\hat{\Delta}}_k\right) = \frac{\left(1 - \frac{m_k}{N_k}\right)s_{\Delta_k}^2}{m_k} + \frac{\frac{m_k}{N_k}\left(\frac{s_p^2}{r} + \frac{s_p^2}{r'}\right)}{m_k}, \tag{20}$$

where

$$s_p^2 = \frac{s_2^2\left(r-1\right) + s_2^{2'}\left(r-1\right)}{\left(\left(r-1\right) + \left(r'-1\right)\right)},$$

$$s_{\Delta_k}^2 = \frac{\sum_{i=1}^{n_k}\left(\hat{\Delta}_k^i - \hat{\Delta}_k\right)^2}{\left(m_k - 1\right)}, \qquad \text{(20A)}$$

and where

s_2^2 = Equation (3B) for year t.

$s_2^{2\prime}$ = Equation (3B) for year $t+1$.

The estimator (16) for the annual change in density is not the most efficient estimator of $\bar{\bar{\Delta}}$ because it does not use the unmatched sites within a year. A separate estimate of change based on the unmatched sites could be calculated and combined using a weighted average similar to Equation (10).

4.0 Annotated Example of Calculations

The purpose of the monitoring is to track salmonid density over time. Seasonal comparisons might be of biological interest, but the real interest is in comparing, for example, spring densities over years. For this reason, this annotated example will illustrate the analysis of two consecutive springtime surveys (Table 4.1). Comparisons of other seasonal surveys (i.e., summer, fall, and winter) over time would be completed analogously.

The expository example consists of a stratified rotational sampling scheme with three strata. Stratum #1 consists of a total of N_1 = 50 sites, of which n_1 = 6 are sampled each year in a 1/3 rotational scheme. The second stratum consists of a total of N_2 = 36 sites, of which n_2 = 6 sites are sampled each year in a 1/3 rotational scheme. The third stratum consists of N_3 = 20 sites, of which n_3 = 6 are sampled each year in a 1/3 rotational scheme (Table 4.1). At each site, a total of r = 2 replicate beach seines are collected on each sampling occasion.

4.1 Density within a stratum

For year t, mean density within a stratum would be calculated using Equation (1) by first averaging across seines within a location and then across locations. For the first stratum in year t, the average density is calculated as follows:

$$\hat{\bar{D}}_k = \frac{\sum_{i=1}^{6}\sum_{j=1}^{2} d_k^{ij}}{6 \cdot 2} = \frac{0.072 + 0.094 + \ldots + 0.101 + 0.094}{12}$$

$$\hat{\bar{D}}_1 = 0.06025.$$

Table 4.1. Expository survey data for tidal freshwater monitoring used in annotated example of calculations.

			Year t		Year $t+1$	
Stratum	N_k	Site	Seine 1	Seine 2	Seine 1	Seine 2
#1	50	1	0.072	0.094		
		2	0.051	0.031		
		3	0.022	0.054	0.049	0.031
		4	0.095	0.055	0.072	0.084
		5	0.019	0.035	0.041	0.009
		6	0.101	0.094	0.079	0.089
		7			0.023	0.041
		8			0.052	0.042
#2	36	1	0.175	0.209		
		2	0.135	0.093		
		3	0.215	0.116	0.150	0.093
		4	0.098	0.013	0.076	0.034
		5	0.321	0.212	0.366	0.111
		6	0.196	0.223	0.137	0.213
		7			0.098	0.107
		8			0.179	0.254
#3	20	1	0.007	0.011		
		2	0.009	0.007		
		3	0.017	0.009	0.011	0.016
		4	0.018	0.023	0.023	0.008
		5	0.011	0.008	0.006	0.001
		6	0.020	0.012	0.009	0.017
		7			0.001	0.004
		8			0.011	0.009

The associated variance is calculated using Equation (3) where

$$\operatorname{Var}\left(\hat{\bar{D}}_1\right)=\frac{\left(1-\frac{6}{50}\right)(0.000818775)}{6}+\frac{\frac{6}{50}(0.00031775)}{6\cdot 2}=0.0001232645$$

where

$$s_1^2=\frac{(0.083-0.06025)^2+\ldots+(0.0975-0.06025)^2}{(6-1)}$$
$$s_1^2=0.000818775$$

and where

$$s_2^2=\frac{(0.072-0.083)^2+(0.094-0.083)^2+\ldots+(0.101-0.0975)^2+(0.094-0.0975)^2}{6(2-1)}$$
$$s_2^2=0.00031775$$

or a standard error of $\operatorname{SE}\left(\hat{\bar{D}}_1\right)$ = 0.0038969.

A similar procedure is used to estimate the mean densities and standard errors of each stratum in both year t and $t+1$ where:

	Year t		Year $t+1$	
Stratum	$\hat{\bar{D}}$	$\widehat{\mathrm{SE}}$	$\hat{\bar{D}}$	$\widehat{\mathrm{SE}}$
#1	0.06025	0.0111025	0.05100	0.0094576
#2	0.16717	0.0283487	0.15150	0.0280655
#3	0.01267	0.0017688	0.00967	0.0020537

4.2 Estuary-wide density

The habitat-specific density estimates need to be combined to produce an overall average fish density using Equation (4) where for year t:

$$\hat{\bar{\bar{D}}}=\frac{\sum_{k=1}^{3}N_k\hat{\bar{D}}_k}{\sum_{k=1}^{3}N_k}=\frac{50(0.06025)+36(0.16717)+20(0.01267)}{(50+36+20)}$$
$$\hat{\bar{\bar{D}}}=0.08759.$$

The estimate assumes areal representation of the habitats can be approximated by the numbers of sites within each habitat.

The variance of the estimate of overall fish density in year t can then be calculated using Equation (6) where

$$\widehat{\mathrm{Var}}\left(\hat{\bar{\bar{D}}}\right) = \left(\frac{50}{106}\right)^2 (0.0111025)^2 + \left(\frac{36}{106}\right)^2 (0.0283487)^2 + \left(\frac{20}{106}\right)^2 (0.0017688)^2$$
$$= 0.0001202$$

or a standard error of $\widehat{\mathrm{SE}}\left(\hat{\bar{\bar{D}}}\right)$ = 0.0109651.

The survey in year $t+1$ can be analyzed as above to produce an overall fish density estimate of $\hat{\bar{\bar{D}}}$ = 0.07733 with a standard error of $\widehat{\mathrm{SE}}$ = 0.0105311.

4.3 Retrospective adjustment in $\hat{\bar{D}}$ for year t

With the rotational data collected in both years t and $t+1$, a retrospective adjustment of the fish densities within habitats and estuary-wide can be calculated for year t. Examination of Table 4.1 indicates there were 4 matched sites in years t and $t+1$ (i.e., sites 3–6) for each of the strata. Conversely, there were two unmatched sites in year t (i.e., sites 1, 2) at each stratum. Equation (7) can be used to obtain a retrospective estimate of density in year t using these matched and unmatched sites.

For the first stratum, the average fish density at the unmatched sites is calculated as

$$\hat{\bar{D}}_{U1} = \frac{\sum_{i=1}^{2}\sum_{j=1}^{2} d_k^{ij}}{2\cdot 2} = \frac{0.072+0.094+0.051+0.031}{4}$$
$$= 0.0620$$

with the associated variance estimate [Equation (3)] of

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_{U1}\right) = \frac{\left(1-\frac{2}{50}\right)(0.000882)}{2} + \frac{\frac{2}{50}(0.000221)}{2\cdot 2}$$
$$= 0.00042557$$

where [Equation (3A)]

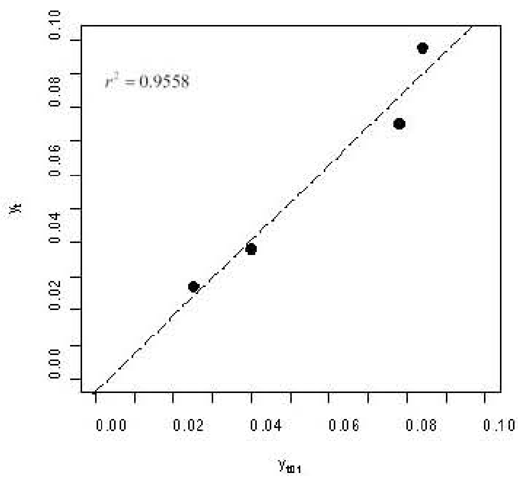
$$s_1^2 = \frac{\sum (0.083-0.0620)^2 + (0.041-0.0620)^2}{(2-1)}$$
$$= 0.000882$$

and where [Equation (3B)]

$$s_2^2 = \frac{\sum (0.072-0.083)^2 + (0.09-0.083)^2 + (0.051-0.041)^2 + (0.031-0.041)^2}{2(2-1)}$$
$$= 0.000221.$$

For the matched sites, the mean site density in year t is regressed against the mean site density in year $t+1$ [Equation (9)], where for the first stratum

$$\begin{aligned}\hat{\bar{D}}'_{M1} &= -0.003641 + 1.110412\,\hat{\bar{D}}_{M2} \\ &= -0.003641 + 1.110412(0.05675) = 0.059375\end{aligned}$$



The variance of $\hat{\bar{D}}'_{M1}$ is calculated using Equation (12), where the MSE from the above regression analysis was MSE = 0.00007071, n = 6, m = 4, and where from Equation (12A)

$$\begin{aligned}s^2_{\bar{D}_M} &= \frac{\sum (0.038-0.059375)^2 + (0.075-0.059375)^2 + (0.027-0.059375)^2 + (0.0975-0.059375)^2}{(4-1)} \\ &= 0.00106756\end{aligned}$$

such that

$$\begin{aligned}\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right) &= \frac{0.00007071}{4} + \frac{0.0010675-0.00007071}{6} - \frac{0.00106756}{50} \\ &= 0.000162468.\end{aligned}$$

Finally, the updated estimate of fish density in year t for the first stratum is calculated using Equation (7)

$$\begin{aligned}\bar{\bar{D}}_1 &= W\hat{\bar{D}}'_{U1} + (1-W)\,\hat{\bar{D}}'_{M1} \\ &= (0.2763)(0.0620) + (1-0.2763)(0.059375) \\ &= 0.06010\end{aligned}$$

where the weight is computed to be [Equation (10)]

$$\begin{aligned} W &= \frac{\widehat{\mathrm{Var}}\left(\hat{\tilde{D}}'_{M1}\right)}{\widehat{\mathrm{Var}}\left(\hat{\tilde{D}}'_{U1}\right)+\widehat{\mathrm{Var}}\left(\hat{\tilde{D}}'_{M1}\right)} \\ &= \frac{0.000162468}{0.00042557+0.000162468} \\ &= 0.2763. \end{aligned}$$

The variance of the retrospective estimate for the first stratum in year t is then calculated as

$$\begin{aligned} \widehat{\mathrm{Var}}\left(\tilde{\bar{D}}_1\right) &= W^2\widehat{\mathrm{Var}}\left(\hat{\tilde{D}}'_{U1}\right)+(1-W)\widehat{\mathrm{Var}}\left(\hat{\tilde{D}}'_{M1}\right) \\ &= (0.2763)^2(0.00042557)+(1-0.2763)^2(0.000162468) \\ &= 0.00011758 \end{aligned}$$

or a standard error of $\widehat{\mathrm{SE}}\left(\tilde{\bar{D}}_1\right)$ = 0.0108.

Similar calculations are performed for the other two strata and summarized below:

Retrospective Adjusted Estimates for Year t

Stratum	$\tilde{\bar{D}}$	$\widehat{\mathrm{SE}}$
#1	0.06010	0.0108
#2	0.16489	0.0252
#3	0.00910	0.0006

Finally, the updated strata-specific estimates are combined to provide an updated "estuary-wide" estimate of mean density for the year t, where

$$\begin{aligned} \tilde{\bar{\bar{D}}} &= \frac{\sum_{k=1}^{3} N_k\tilde{\bar{D}}_k}{\sum_{k=1}^{3} N_k} \\ &= \frac{50(0.06010)+36(0.16489)+20(0.00910)}{(50+36+20)} \\ &= 0.08606. \end{aligned}$$

The variance estimate for $\tilde{\bar{\bar{D}}}$ is calculated as analogous to the standard variance for stratified sampling, where

$$\begin{aligned} \widehat{\mathrm{Var}}\left(\tilde{\bar{\bar{D}}}\right) &= \left(\frac{50}{106}\right)^2(0.00011758)+\left(\frac{36}{106}\right)^2(0.00063740)+\left(\frac{20}{106}\right)^2(0.00000032) \\ &= 0.00009969 \end{aligned}$$

or a standard error of $\widehat{\mathrm{SE}}$ = 0.0100.

4.4 Differences between years t and $t+1$

Using just the paired sites within a stratum for years t and $t+1$, Equation (15) is used to calculate the mean difference in fish density between years as summarized in Table 4.2. Then using Equation (16), the estuary-wide estimate of mean change is calculated where

$$\begin{aligned}\hat{\bar{\Delta}} &= \frac{\sum_{k=1}^{3} N_k \hat{\bar{\Delta}}_k}{\sum_{k=1}^{3} N_k} \\ &= \frac{50(-0.002625)+36(-0.02675)+20(-0.003375)}{50+36+20} \\ &= -0.01096.\end{aligned}$$

To compute the variance for the estimate of estuary-wide change in density, Equation (18) is used where

$$\begin{aligned}\widehat{\text{Var}}\left(\hat{\bar{\Delta}}\right) &= \sum_{k=1}^{3} W_k^2 \widehat{\text{Var}}\left(\hat{\bar{\Delta}}_k\right) \\ &= \left(\frac{50}{106}\right)^2 (0.000018814) + \left(\frac{36}{106}\right)^2 (0.000260721) + \left(\frac{20}{106}\right)^2 (0.000003211) \\ &= 0.00003437\end{aligned}$$

or a standard error of $\widehat{\text{SE}}\left(\hat{\bar{\Delta}}\right)$ = 0.005863. The within-stratum variance for stratum #1 was computed using Equation (20) where

$$\begin{aligned}\widehat{\text{Var}}\left(\hat{\bar{\Delta}}_1\right) &= \frac{\left(1-\frac{m_k'}{N_k}\right)s_{\Delta_1}^2}{m_k} + \frac{\left(\frac{m_k}{N_k}\right)\left(s_2^2+s_2^{2'}\right)}{m_k r} \\ &= \frac{\left(1-\frac{4}{50}\right)(0.0000572292)}{4} + \frac{\left(\frac{4}{50}\right)(0.000366125+0.000199)}{4\cdot 2} \\ &= 0.000018814,\end{aligned}$$

where $s_{\Delta_1}^2$ is calculated as

$$\begin{aligned}s_{\Delta_1}^2 &= \frac{\sum(-0.002-0.002625)^2+\ldots+(0.0135-0.002625)^2}{(4-1)} \\ &= 0.0000572292\end{aligned}$$

and where

Table 4.2. Estimates of mean fish density and differences in fish density between years t and $t+1$ at a site level and a stratum level.

Stratum	Site	t	$t+1$	$\hat{\Delta}^i$
#1	3	0.0380	0.0400	0.0020
	4	0.0750	0.0780	0.0030
	5	0.0270	0.0250	−0.0020
	6	0.0975	0.0840	−0.0135
				$\hat{\bar{\Delta}}_1 = -0.002625$
#2	3	0.1655	0.1215	−0.0440
	4	0.0555	0.0550	−0.0005
	5	0.2665	0.2385	−0.0280
	6	0.2095	0.1750	−0.0345
				$\hat{\bar{\Delta}}_2 = -0.02675$
#3	3	0.0130	0.0135	0.0005
	4	0.0205	0.0155	−0.0050
	5	0.0095	0.0035	−0.0060
	6	0.0160	0.0130	−0.0030
				$\hat{\bar{\Delta}}_3 = -0.003375$

$$s_2^2 = \frac{\sum(0.022-0.038)^2+(0.054-0.038)^2+\ldots+(0.101-0.0975)^2+(0.094-0.0975)^2}{4(2-1)}$$
$$= 0.000366125$$

and where

$$s_2^{2'} = \frac{\sum(0.049-0.040)^2+(0.031-0.040)^2+\ldots+(0.079-0.084)^2+(0.089-0.084)^2}{4(2-1)}$$
$$= 0.000199.$$

The other two within-strata variances are calculated analogously.

5.0 Projected Precision

Precision of the Multi-scale (MS) action effectiveness research project will be defined in terms of relative error, where

$$P\left(\left|\frac{\hat{\bar{\bar{D}}}-\bar{\bar{D}}}{\bar{\bar{D}}}\right|<\varepsilon\right)=1-\alpha. \tag{21}$$

In other words, the desired precision is to have a relative error $\left(\text{i.e., }\left|\frac{\hat{\bar{\bar{D}}}-\bar{\bar{D}}}{\bar{\bar{D}}}\right|\right)$ less than ε, $(1-\alpha)100\%$ of the time. The value of ε is approximately equal to

$$\varepsilon = Z_{1-\frac{\alpha}{2}}\,\mathrm{CV}\left(\hat{\bar{\bar{D}}}\right). \tag{22}$$

Using the preliminary survey data from the fixed and blitz sites in 2009, variance components were estimated (Table 5.1). Under conditions of homogeneity in variances and strata size, the value of ε can be further approximated as

$$\varepsilon = Z_{1-\frac{\alpha}{2}}\frac{1}{\sqrt{lk}}\cdot\sqrt{\frac{\mathrm{CV}_1^2}{n}+\frac{\mathrm{CV}_2^2}{nr}}, \tag{23}$$

where $\mathrm{CV}_1=\frac{S_1}{\bar{\bar{D}}}$ and $\mathrm{CV}_2=\frac{S_2}{\bar{\bar{D}}}$.

The expected values of ε, 95% of the time, were calculated under alternative levels of effort. Either n = 3 or 4 sites per reach–habitat strata and r = 1 or 2 beach seines per site were considered when estimating total salmon density, total Chinook salmon density, or total non-native fish density (Table 5.2). Estimated effort in terms of field-crew days were computed for each of those four alternative monitoring scenarios (Table 5.3).

Table 5.1. Average coefficients of variation (CV) for between-sites/strata (CV_1), and between-seines/site (CV_2) for alternative response variables in tidal freshwater monitoring.

Response variable	Between-sites (CV_1)	Between-seines (CV_2)
Salmonid density	0.3438	1.2718
Chinook salmon density	0.2796	1.3453
Non-native fish density	1.9502	1.9863

Table 5.2. Estimated ε , 95% of the time, as a function of sampling effort and response variable for estimating "estuary-wide" fish density in a monthly sample.

Response variable	# Seines/site (r)	# Sites/stratum (n)	ε
Salmonid	1	3	0.4304
	2	3	0.3145
	1	4	0.3727
	2	4	0.2734
	2	5	0.2436
	3	5	0.2051
Chinook salmon	1	3	0.4489
	2	3	0.3239
	1	4	0.3887
	2	4	0.2805
Non-native fish	1	3	0.9093
	2	3	0.7851
	1	4	0.7875
	2	4	0.6799

Table 5.3. Estimated field-crew days needed for alternative levels of monitoring effort.

# Seines/site (r)	# Sites/stratum (n)	Total # of sites	Total # of seines	Field-crew days
1	3	36	36	2.4
2	3	36	72	3.0
1	4	48	48	3.2
2	4	48	96	4.0

6.0 Test for a Regional Trend

6.1 Test of slope

Using a straight-line regression of annual response versus year (i.e., t = 0, 1, 2, 3, 4), the null hypothesis of no increase in salmon density can be written as

$$\mathrm{H_o}: \quad \beta \leq 0 \tag{24}$$

vs.

$$\mathrm{H_a}: \quad \beta > 0,$$

where β is the slope of the regression model $\hat{\bar{\bar{D}}}_i = \alpha + \beta t$. The null hypothesis can be tested using the t-statistic

$$t_{m-2} = \frac{\left|\hat{\beta} - 0\right|}{\sqrt{\dfrac{\mathrm{MSE}}{\sum_{i=1}^{m}\left(t_i - \bar{t}\right)^2}}}. \tag{25}$$

6.2 Power calculations

In the special case of a five-year test of trends:

a. $\sum_{i=1}^{m}\left(t_i - \bar{t}\right) = 10$ for $t_i = (0,1,2,3,4)$

b. $E(\mathrm{MSE}) = \sigma_N^2 + \overline{\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}$

where

σ_D^2 = natural variation in response,

$\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)$ = variance in the annual estimate (for a specific month) of mean fish density.

c. $\beta = D_0(1 + \Delta)$ for a linear change in response $\bar{\bar{D}}_i = \bar{\bar{D}}_0(1 - i\Delta)$

and where

Δ = annual fractional increase in mean fish density,

$\bar{\bar{D}}_0$ = average fish density in the first year.

Taking into account factors a – c, the noncentrality parameter associated with the noncentral F-distribution under $\mathrm{H_a}$ can be written as

$$\Phi_{1,3} = \frac{1}{\sqrt{2}} \cdot \frac{\left|\bar{\bar{D}}_0 \Delta\right|}{\sqrt{\dfrac{\sigma_D^2 + \mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}{10}}}. \quad (26)$$

Currently, we have no estimate of the natural variation in mean fish density (i.e., σ_D^2). Until further information is collected, it will be assumed the natural variation is near zero (i.e., $\sigma_D^2 = 0$), then the noncentrality parameter can be rewritten as

$$\Phi_{1,3} = \sqrt{5} \cdot \frac{|\Delta|}{\mathrm{CV}}, \quad (27)$$

where $\mathrm{CV} = \dfrac{\sqrt{\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}}{\bar{\bar{D}}}$.

6.2.1 Example: Power calculations for detecting a five-year increase of 25%

Assuming n = 4 replicate sites per reach–habitat stratum and m = 2 seines/site, the projected CV for an estuary-wide estimate of mean fish density is 0.1395 (= 0.2734/1.96) (Table 5.2). Consider a 0.25 increase in mean density over five years (i.e., 0.25 = (0.0625) × 4 changes in five years of monitoring), then

$$\Phi_{1,3} = \sqrt{5} \cdot \frac{|0.0625|}{0.1395} = 1.0018,$$

which corresponds to a statistical power of $1-\beta$ = 0.48, at α = 0.10, one-tailed.

6.2.2 Example: Detecting a 10-year increase of 50%

The noncentrality parameter for a 10-year test of a linear trend is

$$\Phi_{1,8} = \frac{1}{\sqrt{2}} \cdot \frac{\left|\bar{\bar{D}}_0 \Delta\right|}{\sqrt{\dfrac{\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}{82.5}}}$$

or

$$\Phi_{1,8} = \sqrt{41.25} \cdot \frac{|\Delta|}{\mathrm{CV}}.$$

The power to detect a 50% increase in estuary-wide, mean salmonid density within 10 years can be calculated where Δ = 0.05556 [i.e., 0.05556 (9) = 0.50], where

$$\Phi_{1,8} = \sqrt{41.25} \cdot \frac{|0.05556|}{0.1395} = 2.5580.$$

Reading the noncentral *F*-table, $1-\beta$ = 0.98 at α = 0.10, one-tailed. This power calculation is based on the assumption that the average CV for the future estimates of estuary-wide, mean salmonid density will be 0.1395 and σ_D^2 = 0.

7.0 Recommendations

Precision calculations based on preliminary survey data on salmonid density suggests "estuary-wide" (i.e., reaches D, E, F, and G) estimates of mean density might be calculated with a precision of $\pm$ 27.34, 95% of the time (i.e., CV = 0.1395), with n = 4 sites/stratum and m = 2 seines/site. Lesser effort will produce values of ε = 0.30 – 0.43. Power calculations suggest with that level of annual precision, the monitoring project would have a statistical power of $1-\beta$ = 0.98 at α = 0.10, one-tailed, of detecting a 50% increase in mean salmonid density over a 10-year period (i.e., assuming σ_D^2 = 0).

Additional work should be done to estimate the interannual variation in density $\left(\sigma_D^2\right)$ so that the power calculations can be refined.

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